(2)

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

AN ASSESSMENT OF RELEVANT
COSTS IN THE WILSON EOQ MODEL

by

Morten Meinich

December 1988

Thesis Advisor: Shu S. Liao

Approved for public release; distribution is unlimited.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) Code 54	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

AN ASSESSMENT OF RELEVANT COSTS IN THE WILSON EOQ MODEL

12 PERSONAL AUTHOR(S)
Meinich, Morten

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1988 December	123

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the US Government

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Inventory models, holding costs, ordering cost, simulation

19 ABSTRACT (Continue on reverse if necessary and identify by block number) This thesis presents a framework for determining ordering and holding costs as parameters in Economic Order Quantity (EOQ) type inventory models. The concept of relevant costs is discussed from a theoretical perspective.

Regression analysis was used to compare annual ordering cost and the number of orders at Ships Parts Control Center (SPCC), Mechanicsburg. The relationship was found to be inverse over the years 1976-1988. This indicates that a critical assumption for the use of EOQ models is being violated at SPCC.

Various probability distributions were used to simulate how total variable cost was affected by changes in the holding cost parameter. The results indicate that the feasibility of applying different holding cost rates for various items should be further explored.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Shu S. Liao	22b TELEPHONE (Include Area Code) 408-646-2505 22c OFFICE SYMBOL 54Lc

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete — SECURITY CLASSIFICATION OF THIS PAGE

© U.S. Government Printing Office 1986—606-24.

(Approved for public release; distribution is unlimited)

An Assessement of Relevant Costs in the Wilson EOQ Model

by

Morten Meinich
Lieutenant Commander, Royal Norwegian Navy

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1988

Author: Morten Meinich
Morten Meinich

Approved By: Shu S. Liao, Thesis Advisor

Thomas P. Moore
Thomas P. Moore, Second Reader

David R. Whipple, Jr., Chairman,
Department of Administrative Sciences

K.T. Marshall
Kneale T. Marshall,
Dean of Information and Policy Sciences

ABSTRACT

This thesis presents a framework for determining ordering and holding costs as parameters in Economic Order Quantity (EOQ) type inventory models. The concept of relevant costs is discussed from a theoretical perspective.

Regression analysis was used to compare annual ordering cost and the number of orders at Ships Parts Control Center (SPCC), Mechanicsburg. The relationship was found to be inverse over the years 1976-1988. This indicates that a critical assumption for the use of EOQ models is being violated at SPCC.

Various probability distributions were used to simulate how total variable cost was affected by changes in the holding cost parameter. The results indicate that the feasibilty of applying different holding cost rates for various items should be further explored.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

The use of models for inventory management is a well established technique in the commercial as well as in the military sector. The basic economic order quantity (EOQ) model was first published in 1915[1], and has since gained widespread acceptance.

The standard theoretical presentation of the model assumes that holding, ordering, and stockout costs are known. However, the determination of these cost categories is no easy task in practice. This thesis will explore some of the difficulties involved through an analysis of the parameters currently used for holding and ordering costs at Ships Parts Control Center (SPCC) in Mechanicsburg.

As of June 1986 the number of line items managed by SPCC totalled 544,000. Theoretically holding and ordering costs for each of these could be different, and thus require as many different specific parameters as there are different items. An attempt to optimize the inventory management of each separate line item would require computer capacity that far exceeds what is available in the US Naval Supply System. Therefore, average values have been applied for groups of items with similar characteristics.

The determining factors for the the grouping of items, and thus for determining what parameter to use, are primarily the acquisition method, the value of annual demand, whether the item in question is defined as a consumable or a repairable, and whether there are constraints such as limited shelf life or special storage requirements.

---

[1]Ford Harris, Operations and Costs, Factory Management series (Chicago, A. W. Shaw Co., 1915), pp.48-52.

B. OBJECTIVES

The objective of this thesis is to supplement the textbook approach by presenting a methodology to determine parameter values for ordering and holding costs in the EOQ models. The nature of holding and ordering costs is described theoretically, and the concept of relevant costs is emphasized. Problems with applying this concept in practice, specifically as it relates to identifying relevant costs for managing inventories at SPCC, are examined. Current policies are discussed in terms of the theoretical foundation for the use of economic order quantity models.

C. RESEARCH QUESTIONS

The primary research question is how to determine the values for holding and ordering costs on the basis of sound theoretical principles. This question requires establishing a framework to determine what cost elements should be included in each of the categories of holding and ordering costs.

A subsidiary question is to compare the framework to the methodology presently used for determining these parameters at an Inventory Control Point in the US Navy. Specifically, ordering cost data from SPCC are analyzed. The assumption that total annual ordering cost is a linear function of the number of buys is tested.

The third research question is to evaluate the economic implications of uncertainty in the parameter estimates. The cost of constraining the EOQ model, in terms of number of annual buys, is discussed as a part of question three.

D. SCOPE, LIMITATIONS AND ASSUMPTIONS

This study is concerned with the cost aspect of the economic order quantity model known as the Wilson EOQ model, specifically the determination of holding and ordering costs.

More sophisticated versions of the model also include a third category, namely a stock-out cost. A reasonable discussion of this cost is beyond the scope of this thesis. Furthermore, the stock-out cost can be excluded from the analysis because it is determined independently of the ordering costs and holding costs.

The EOQ model is the basis for US Navy inventory management, although imposed constraints on the model affect a majority of the line items. No attempt is made in this thesis to evaluate whether or not EOQ models are the best type to use in a military environment.

Presently four different values for ordering costs and two different values for holding costs are used as parameters in SPCC's EOQ models. This study treats the present classification as given. The possibility of more discriminatory parameter settings will be addressed, but without attempting to explore all the ramifications of such a strategy.

This thesis discusses the procurement and inventory management of items at SPCC. However, the problems of determining correct parameters, and the economic consequences of constraining the order quantities are general in nature.

E. LITERATURE REVIEW AND METHODOLOGY

Research question number one is to identify relevant costs. This is done through a study of literature in the fields of inventory management, accounting, logistics and operations research.

Research question number two is a comparison between the established theoretical framework and current policies, and practices for inventory management at SPCC. Ordering cost data from SPCC are analyzed, using standard regression techniques, and through personal interviews.

Research question number three, evaluating the economic implications of uncertainty in the parameter estimates, is

answered by means of simulation. An EOQ model was built, using LOTUS 1-2-3 software, and changes in total variavle cost were simulated based on various holding cost rates.

F. DEFINITIONS AND ABBREVIATIONS

Administrative order cost (A), ordering cost, and cost to order are interchangeably used in the literature. The term includes all the cost elements that are associated with the placement of an order of material, which will be used to replenish an inventory, except the actual cost of the material itself. The basic EOQ model assumes that the ordering cost is independent of the ordering quantity, and that total ordering cost (TOC) is a linear function of the annual number of purchase actions.

Holding cost, sometimes called carrying cost, is the sum of all the cost elements incurred as a function of storing materials. In the EOQ formula, the holding cost is assumed to be a fixed proportion of the value of the item. It is also assumed to be a linear function of time. The holding cost can include out of pocket expenses as well as opportunity cost, and is usually expressed as a percentage (I) per year of the price (C) of the item.

Total variable cost (TVC) is the sum of ordering and holding costs. The lowest total variable cost is incurred when the purchase quantity equals the economic order quantity (EOQ). If either a larger or a smaller quantity is bought, TVC will increase by some amount, in this thesis denoted the X-cost.

G. SUMMARY OF FINDINGS

A large proportion of the holding cost is represented by the cost of capital. Because money is tied up in inventories, alternate investments cannot be undertaken. The profit thus foregone is defined as an opportunity cost. This thesis concludes that the opportunity cost concept should be

applied to capital cost. However, care should be taken so as not to include the rate of inflation in the capital cost. The reason is that inflation is a pure monetary phenomenon, and does not affect real assets, such as inventories. A proper measure of capital cost should therefore be the rate of return on alternative (financial) investments less the rate of inflation.

Data from Ships Parts Supply Center indicate that the present method for determining the ordering cost parameters is inadequate, as it does not effectively recognize marginal costs. Thus, one of the assumptions for using an EOQ type of model at SPCC is violated.

The original objective of the EOQ model was to determine mathematically the optimal inventory policy. Manipulating the parameters of the model, or imposing constraints on the solution, will lead to suboptimal results in terms of monetary costs represented in the objective function. Nonetheless, these are options for the management to force the model to come up with solutions that for some reason seem attractive. This study includes a flexible spreadsheet model that will calculate the X-cost incurred by imposing such constraints. Thus, trade-off analyses are easily facilitated.

H. ORGANIZATION OF THE THESIS

Chapter II presents the theoretical framework for the use of an EOQ type inventory model. More specifically, those cost elements that should be included when determining proper holding and ordering cost rates are identified.

Chapter III briefly describes assumptions and policies for applying inventory models at SPCC. External and internal constraints on the computation of EOQ are discussed. Chapter IV describes the data and the methodology used for the analysis of ordering, and holding cost parameters. Chapter V presents results and interpretations of the findings, and Chapter VI contains conclusions and recommendations.

II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This chapter is divided into three sections. The first section will present the Wilson EOQ model, and the basic assumptions for the use of this model. The last two sections will discuss what elements should be included in the parameters for the holding cost and the ordering cost.

A. WILSON'S EOQ MODEL

1. Assumptions

Wilson's EOQ model, also known as "the square root formula", attempts to minimize the sum of ordering and holding costs under a given set of assumptions. The sum of these costs is frequently called total variable cost (TVC). Total variable cost is a function of how frequently orders are placed. It is also a function of mean inventory level. In its simplest form the model states that the optimal order quantity for an item can be found by the following formula:

$$EOQ = \sqrt{\frac{2\,A\,D}{C\,I}}$$

EOQ: Economic order quantity
A: Cost of placing an order
D: Annual demand in number of items
C: Replacement cost per unit of an item
I: Cost of holding one item in stock for one year expressed as a percentage of C

As can readily be seen from the formula, EOQ will increase for an increase in the parameters for ordering cost and demand, or a decrease in the parameters for replacement cost and the holding cost rate.

To be truly optimal the formula requires a number of assumptions to be met. Tersine [Ref. 1:p 94] suggests the following:

1. The demand rate is known and constant.
2. The lead time is known and constant.

3. The entire lot size is added to inventory at the same time.

4. No stockouts are permitted; since demand and lead time are known, stockouts can be avoided.

5. The cost structure is fixed; order/setup costs are the same regardless of lot size, holding cost is a linear function based on average inventory, and no quantity discounts are given on large purchases.

6. There is sufficient space, capacity, and capital to procure the desired quantity.

7. The item is a single product; it does not interact with any other inventory items (there are no joint orders).

In addition, the inventory system is considered to be perpetual in nature. At first glance these assumptions may seem too restrictive for the model to be useful in practical applications. However, this is not so. The EOQ model has proved to be rather robust, and has won widespread acceptance. Refinements of the model have enabled most of these assumptions to be relaxed. In actual applications of the model, the constraints have been relaxed in the following manner:

1. The demand rate can be estimated by some probability distribution.

2. The lead time can be estimated by some probability distribution.

3. Additions to inventory can be instantaneous or take place at a given rate. The latter case is frequently associated with production situations, so that inventories build up over time until a maximum level is reached. Demand then draws down inventories and the cycle starts anew.

4. Stockouts are permitted. The objective of the inventory system then becomes the minimization of the sum of holding, ordering and stockout costs.

5. Where quantity discounts are given, or ordering cost is a stepwise function of the ordering quantity, the EOQ model can be applied heuristically, i.e., the best feasible solution is found through an iterative process.

6. Constrained resources can be handled through the use of the mathematical technique known as the Lagrange-multiplier method.

7. Minimizing the cost of joint orders is possible, although computationally cumbersome. In actual attempts a computer would be required.

In practice, the time perspective should cover at least one complete order cycle. These adaptations enable EOQ models to solve quite complex inventory management problems in a theoretically sound manner. However, the quality of the solutions will depend on the quality of the inputs to the model.

Much attention has been given to the problem of forecasting demand accurately. Yet, a look at the Wilson EOQ model reveals that inaccurate estimates of the parameters for demand, price, holding costs or ordering costs are all equally important in terms of the model's performance. This is so because the four parameters in the model are treated as constants. The model includes a ratio of two products, and only the ratio itself is of any importance in terms of calculating the EOQ.

2. Sensitivity of the EOQ Model

The EOQ model is known to be fairly insensitive to errors in the parameter estimates, which may be one reason for the model's widespread use. Let the sum of the ordering cost and holding cost incurred with erroneous parameter estimates be denoted TVC^T. Further, let the TVC error fraction be defined by the following formula:

$$\text{TVC error fraction} = \frac{TVC^T - TVC}{TVC}$$

Tersine [Ref. 1:pp. 114-120] shows mathematically the relationship between errors in the parameters and the TVC error fraction. As an example he points out that an error in any single parameter by a factor of two, only will result in a TVC error fraction of 6.07 percent, provided the other estimates are correct. This clearly shows that the square root formula has a considerable dampening effect on errors in individual parameters in the model.

Erroneous parameter estimates will result in erroneous order quantities. The relationship between total

variable cost and these erroneous order quantities can be expressed mathematically. Let the Wilson economic order quantity be denoted Q, and the actual buy quantity be denoted aQ. Further, let optimal total variable costs be denoted TVC and let the actual costs incurred if aQ is bought be called TVC^T. The relationship is then:

$$\text{TVC error fraction} = \frac{(a-1)^2}{2a}$$

The insensitivity to errors in the parameter estimates is graphically portrayed in Figure 1. The actual holding cost rate (I) is assumed to be 23 percent. When this rate is used as a parameter, TVC^T and TVC are identical, and the TVC error fraction is zero. However, if any other rate is used for the holding cost rate, the TVC error factor is as indicated on the abscissa.

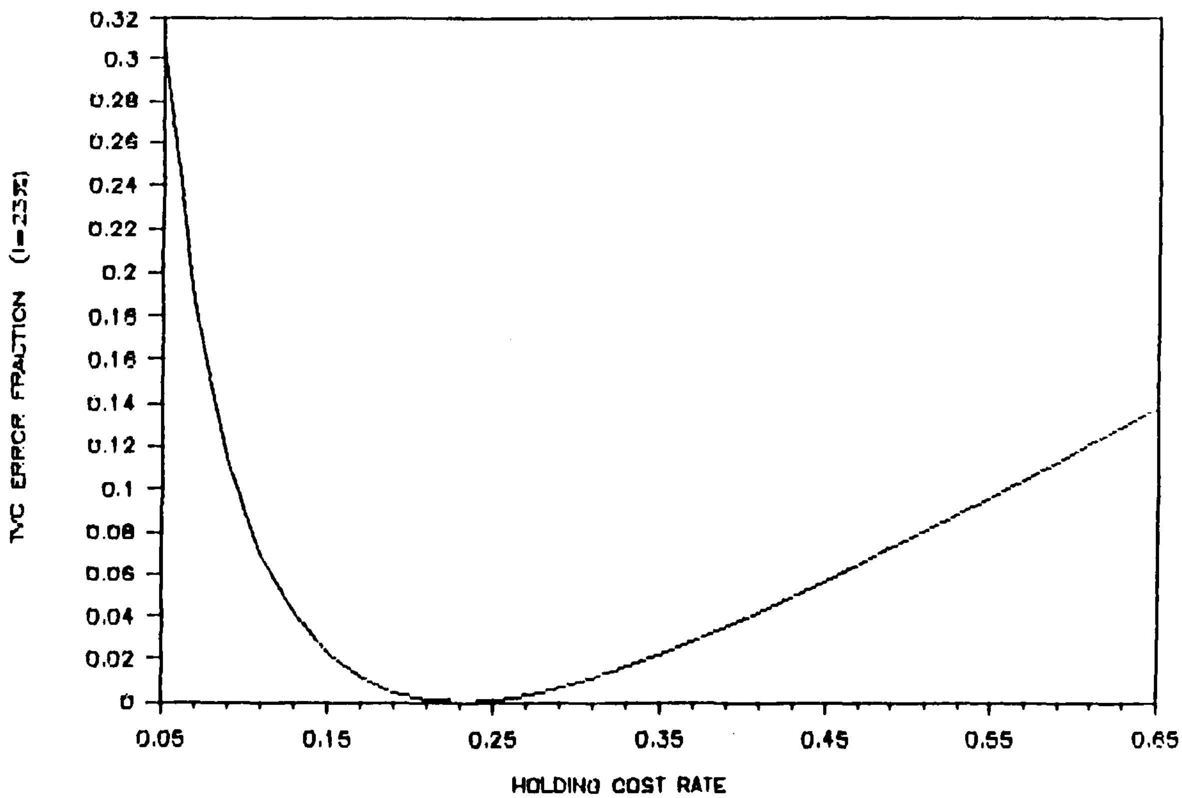

Figure 1. Insensitivity to Errors in Parameters

Figure 1 assumes that all parameters, except for the holding cost rate, are estimated correctly. Further, no constraints are imposed on the EOQ calculations. 23 percent is chosen as a point of reference because this is the holding cost rate currently used at SPCC.

The relationship between the individual parameters and the calculation of EOQ has been discussed. It should therefore be readily appreciated that curves similar to the one presented in Figure 1 can be constructed for the other parameters in the model as well. Errors in individual parameters will influence the actual buy quantity. Consequently, the relationship between the actual and the optimal buy quantities can be graphically depicted in a similar manner.

Only in rare cases are the parameters of the EOQ model exactly known. Therefore, errors in the order quantities are to be expected. Because of the shape of the curve in Figure 1, it is generally recommended to err on the high side. That is, under uncertainty it is better to buy more than the economic order quantity rather than less.

While the robustness of the model is very useful from a practitioner's point of view, it should not discourage attempts to determine the various parameters as correctly as possible. In order to do so, it is important to understand how total variable cost changes with respect to changes in the order quantities.

3. Relevant Costs

This section focuses on the determination of relevant costs, i.e., elements that should be included in determining ordering and holding costs as parameters in EOQ models. In the context of the EOQ model, relevant costs are used synonymously with marginal and incremental costs. The stockout cost is not addressed. This should not be interpreted as an indication that the stockout cost is less

important than the other two categories. The reason is simply that the stockout cost is extremely difficult to ascertain, particularly in a military environment.

There is an extensive literature about how to value inventories, and to find the associated costs of holding such. However, most of this literature presents holding cost from an accounting point of view. The focus of this literature has been on the tax aspect and the eventual impact on the financial statement.

Determining the correct parameters for the EOQ model requires a somewhat different approach. The reason is that the objective in this case is not to find the exact costs of holding inventories in a past period. Instead, the problem is to determine what costs are affected by future changes in the inventory level.

Briefly stated, three principles apply for the determination of relevant costs:

1. Only future costs, or the avoidance of future costs, matter.
2. Costs that do not change as a function of changes in the inventory levels or the ordering frequency can be ignored.
3. Changes in costs may be of a different magnitude for an increase or a decrease in the inventory level.

Clearly, applying these principles may be easier said than done. Stockton [Ref. 2: p.12] expresses the following:

> Collecting meaningful cost data in business firms is an area full of personal prejudices, pitfalls, and accounting conventions. Differentiating between direct and indirect costs, handling joint costs and allocating overhead on an equitable basis have always been troublesome issues for accountants and decision makers alike. Unfortunately cost data for use in inventory models is no exception to these difficulties.

A distinction that is frequently made in the accounting literature is one between fixed and variable costs, see for instance Jannis, Poedtke and Ziegler [Ref. 3:p. 87]:

> In the classic EOQ there are four variables that determine the order quantity, namely: (1) the forecasted annual demand for the item expressed in units, (2) the

variable expenses associated with issuing and following up an order (whether for purchase or production) in terms of dollars per order, (3) the expense of carrying inventory for one year, expressed as a percentage and (4) the variable cost of one unit. It should be noted that all expenditures considered in an EOQ calculation are variable or marginal costs, sometimes referred to as out-of-pocket costs.

> In determining whether an expenditure is variable, it is necessary to determine how a specific item would be influenced by the decision to change the number of orders issued or the amount of material carried in inventory.

The last paragraph in the above quotation correctly identifies the principles for determining relevant costs. However, the treatment of variable costs, marginal costs and out of pocket expenses as synonyms is confusing.

The categorization of costs as fixed or variable often depends on the time perspective. In general, the longer the time period, the more cost elements can be regarded as variable because a greater number of alternative actions are available. Therefore, if the classification shall be useful, it is necessary to determine the time period over which alternative actions can be compared. Moreover, the classification is not absolute. This point is acknowledged in the following statement by the same authors [Ref. 3:p. 95]:

> The fixed - variable segregation may be a valid indication of the tendencies of the expenditures to behave in the way described, but they cannot necessarily be fitted neatly into one category or another - or even a third, middle ground category of semifixed or semivariable.

More important than being able to classify costs as variable or fixed, is to be aware of the fact that variable and marginal costs may have different meanings. Variable costs are frequently thought of as costs that vary directly in some proportion to the change in activity level. Typically, some costs vary more as a stepwise function. These costs remain fairly stable over a given interval of activity, and then jump up or down to a new fairly stable level. Such sudden jumps in costs are certainly relevant for

decision making, and should be considered as part of the marginal cost in the range where the steps take place.

Marginal costs will always include variable costs, and may sometimes also include the stepwise increase or decrease in semifixed or fixed costs.

Stockton attempts to describe relevant costs in the following manner [Ref. 2:p. 13]:

> Inventory models focus on those costs whose magnitude will change directly and immediately if a proposed decision rule is adopted. This means that "out of the pocket" costs are usually relevant but not such fixed costs as depreciation and salaries. Which costs are relevant also depends upon the scope of the study and the time period being considered.

Unfortunately, it is not enough to consider out-of-pocket expenses only. Opportunity costs, although frequently quite illusive, are nonetheless relevant. For instance, if available space in the warehouse could be rented, then not doing so represents an opportunity cost that should be considered. Similarly, if the employees in the warehouse could do other productive work in the organization, or even be laid off on short notice, it is usually correct to allocate salaries to inventory costs in proportion to the work done in this area.

Probably the largest component of inventory holding cost is the cost of capital tied up in inventories. This costs is typically not an out-of-pocket expense, but rather an opportunity cost. In the EOQ model, the opportunity costs are as relevant as the out-of-pocket expenses, and should therefore be included in the term marginal cost. This point is further elaborated in a discussion of capital cost.

The ease, with which marginal costs can be identified in practice, will frequently be a function of the variability of the activity level. The impact of a relatively small change may be easily recognized in a stable environment. Thus, good estimates for marginal costs may be obtained. On the other hand, in a volatile environment,

there may, at times, be considerable over- or under-utilization of resources in the organization. In that case, the impact of a marginal change in activity may not be readily ascertained.

Some costs may be ignored in the EOQ model because they do not affect the order quantity. A typical example is the cost of the item itself. Provided there is no quantity discounts, inclusion of the purchase costs in the total cost equation will not change the optimal solution.

The fact that some costs tend to increase more easily than they decrease should be recognized when determining relevant costs. During an expansion of the activity, additional costs tend to be incurred. The number of employees and facilities and the amount of equipment increase. A subsequent reduction of the activity level may not lead to a similar reduction in the costs. Salaries and long term leases are examples of costs that may be semifixed, i.e., that cannot be avoided instantaneously.

The remainder of this chapter will describe what cost elements should be considered when trying to determine the parameters for holding and ordering costs as correctly as possible. Whether they in fact are relevant or not, in a particular application of the model, would have to be determined on a case by case basis.

B. HOLDING COSTS

Holding costs are usually defined as the cost of holding inventory for one year. Typically they are expressed as a percentage of the price of the item. This percentage may be interpreted as the cost of holding a dollar's worth of inventory over a period of one year.

Van DeMark [Ref. 4:p. 148] uses the term "K-cost" for holding cost and sets up the following two criteria:

1. The K cost is incurred after you have inventory.
2. The K cost varies with the size of the order.

These two criteria give a good intuitive feel for what cost elements should be regarded with respect to holding cost. But as later will be pointed out, they should not be taken to apply to all situations.

According to Lambert [Ref. 5:p. 60], the holding cost can be divided into four elements: capital costs, space costs, inventory service costs, and inventory risk costs. The assumption is that costs accrue as a linear function of time, i.e., if storage time doubles so do storage costs. The elements of the holding cost may start to be incurred at different points in time. Costs associated with risk start to accrue from the moment title of the items is transferred from the seller to the purchaser. Capital cost is incurred as a function of payment, and space and inventory service costs are typically incurred from the moment the lot is received. For practical purposes, however, the assumption that holding costs accrue linearly as a function of time seems reasonable.

1. Capital Costs

Of the various elements that constitute holding cost, the most important one is probably the capital cost. Goodman [Ref. 6:p. 219] defines capital costs as:

> The cost of capital refers to that amount of money which a company, as a result of accepting a proposal, is expected to pay to and/or reinvest for the suppliers of funds during the life of the proposal, over and above the amount of funds required to initially finance the proposal.

Ballou [Ref. 7:p. 361] offers the following comments on capital costs:

> Capital costs refer to the cost of the money tied up in inventory. This cost may represent as much as 80 percent of total inventory carrying cost, yet is the most intangible and subjective of all the carrying cost elements.

The magnitude of the capital cost element will naturally depend on the way it is measured. Several concepts have been suggested, depending on whether inventories primarily are regarded from a cost perspective or an

investment perspective. The reasons for holding inventories should therefore be clarified.

Ballou suggests four different reasons for holding inventories [Ref. 7:p. 357]:

1. Speculation; the acquiring of inventories in anticipation of future price increases.
2. Inventories in transit in the logistic channel, frequently called pipeline inventories.
3. Regular or cyclical stocks which are necessary to meet average demand during the time between successive replenishments.
4. Safety stock which acts as a hedge against variability in demand during lead time.

The term "speculation" has a negative connotation to it. It should therefore be emphasized that in this context, the motive is entirely legitimate. Typically, inventory build-ups are done when the supplier is known or expected to raise prices in the near future. If the supplier is known or expected to end production of an item, this may be another reason to increase inventory levels. Because of the high costs of starting a new production run, it may be beneficial to buy a sufficiently large quantity to last for the remaining time the item will be needed.

Unlike the other reasons, the speculation motive for holding inventories is not concerned with minimizing inventory levels subject to economic and operational constraints. Therefore, the costs of holding inventories for speculative reasons should be compared to any other investment alternative available to the organization.

As regards the other motives for holding inventories, different views exist. Some regard inventories as necessary byproducts of doing business. As such, inventories are only means to achieving profitable operations. Therefore, inventory holding costs should be treated as any ordinary cost. According to this line of reasoning, the actual rather than the opportunity cost of capital should be used.

A different point of view is to stress that alternative investment opportunities exist. Therefore, the only justification for holding inventories is as a means to reaching a desired profitability goal in terms of return on all employed capital. Which is the right point of view is a matter of opinion, and also depends on whether alternative investment opportunities actually exist or not.

A range of values for the cost of capital tied up in inventories has been suggested. In general these can be divided into three categories: the average cost of capital; the hurdle rate; and the average rate of return on employed capital.

a. The Average Cost of Capital

The rationale for using the average cost of capital is based on the view of inventories as a prerequisite for doing business. By this concept, the decisive factor would be how additional inventories are to be financed. Among the alternatives are equity, short term financing or long term financing. Usually it is hard to match the type of financing to varying inventory levels, particularly since different items in stock have different turnover times. Therefore, the most common measure in this category is the average cost of capital employed.

The average cost of capital can be computed in two ways, depending on how equity is treated. If the average of all capital employed is sought, equity should be included. No cost should be attached to equity since the average cost of capital is concerned with the actual cost, not the opportunity cost. The other alternative is to compute the actual cost of external financing only.

b. The Hurdle Rate

Mao [Ref. 8:p. 373] defines the hurdle rate as "the rate of return on the most lucrative investment foregone." The idea is that capital is limited.

Consequently, additional spending on inventories excludes alternative investment opportunities of the same magnitude. Therefore, the cost is equal to the lost opportunity.

Hadley and Whitin [Ref. 9:p. 13] express a similar view. They claim that:

> ... an opportunity cost ... is the cost incurred by having capital tied up in the inventory rather than having it invested elsewhere, and it is equal to the largest rate of return which the system could obtain from alternative investments.

This line of reasoning is consistent with the concept of marginal cost, and is in this context regarded as the concept that most accurately reflects the true capital cost.

c. The Average Rate of Return

The average rate of return is similar to the hurdle rate, in the sense that the cost of holding inventories is recognized as an opportunity cost. In other words, the measure is not the actual cost of tying up capital in inventories, but rather an estimate of the rate of return an alternative investment of the same magnitude would yield. The average rate of return may be more readily available than the hurdle rate, and thus easier to apply.

The holding cost rate in the EOQ model is supposed to reflect a future cost. The use of historical data to compute the average rate of return is therefore inappropriate in a changing environment. If the average rate of return is applicable, the expected rather than the historical average rate of return should be used.

2. Choosing a Measure of Capital Cost

There is clearly no consensus as to what the proper measure of capital costs should be. The following paragraphs describe a practical way to choose a capital cost to use in the EOQ model. Start with a rough estimate of the magnitude of the potential investment in additional inventories, and estimate for how long the capital will be tied up. (The exact magnitude of the investment cannot be calculated as it

depends on what holding cost factor will eventually be used). The next step is to assess, as realistically as possible, the best investment alternative for the calculated amount over the time period the inventory will be kept. This investment alternative is a measure of the opportunity cost. The higher of this opportunity cost and the actual cost of any external financing should be chosen. Since risk is considered as a special element of inventory holding costs, it should not be included when evaluating the capital cost element. Comparable investment alternatives should, in essence, also be risk free.

Theoretically, a different holding cost rate might be applied each time items are purchased, because the alternative investment opportunities are constantly changing. However, too frequent changes in the holding cost rate would be impractical. This is particularly the case as TVC is not impacted much by small changes in the parameter. The calculated capital cost should therefore be applied for some predetermined length of time.

An interesting approach to the treatment of capital cost is suggested by Demski and Feltham. [Ref. 10:p. 99].

> Many inventory models, such as the traditional EOQ model, include the cost of "capital tied up in inventory" as part of the storage cost. However, in a complete analysis there is no need to introduce a special cost for this item; it is taken into consideration by the fact that we evaluate all cash flows in terms of their present value, and earlier acquisition results in earlier payment for these materials.

Nonetheless, in order to determine the present value, a proper discount factor has to be determined. Conceivably, any of the alternatives mentioned so far could be used to find this discount factor. Thus, the problem of identifying a realistic cost of capital cannot be avoided.

The determination of capital costs in the public sector is a special case, and will be discussed in some detail in Chapter III.

3. The Effects of Inflation

Inflation can be defined as a general rise in prices, or conversely as a general decrease in purchasing power. A certain amount of money can, over time, gradually buy less and less of a given good. To compensate for this erosion of purchasing power, the market interest rate includes an inflation premium.

Brigham and Gapenski [Ref. 11:pp. 68-69] express the determination of the market interest rate on a debt security as: $k = k^* + IP + DRP + LP + MRP$

Here:
k= stated or nominal rate of interest
k* = pure, or real, rate of interest
IP = inflation premium
DRP = default risk premium
LP = liquidity, or marketability, premium.
MRP = maturity risk premium

Investors can choose between investing in financial assets, or investing in an inventory of durable goods. For any financial investment alternative to be accepted, it must yield a rate of return which is at least as high as the prevailing market interest rate. On the other hand, there is no need to apply the inflation premium to an inventory of durable goods. The reason is that the value of an inventory would increase over time in monetary terms, provided no obsolescence occurs. In other words, the amount required if the same number of items were to be acquired at a later point in time would have to be higher. The rate of this increase in value would exactly offset the rate of inflation for a typical item. Since obsolescence is accounted for separately, as a part of the inventory risk cost, one can assume that the inventory eventually will be needed.

The concepts of average capital costs, the average return on investments, and the hurdle rate are all tied to return in nominal terms. No adjustments for the effects of inflation on real assets have been suggested in the referenced literature. Recent estimates suggest that a rate

of inflation of five to six percent annually can be expected in the years to come. Inflation is thus a major factor in the aggregation of the market interest rate, and in the required rate of return on investments. This should be recognized in determining the cost of capital to use in the EOQ model. Consequently, although several concepts may be applied to find the cost of capital, none of these should include a premium for inflation.

4. Space costs

Space cost is a common term for all costs associated with the physical storage of an inventory. Typical costs include warehouse rent; or ownership costs such as depreciation, heating and utility, security, etc.
The cost of special environments such as specially controlled temperature, humidity, or security ought to be considered.

In the case of rented or leased warehouse space, total space cost usually varies as a direct function of the occupied space. For privately owned warehouses some further analysis may be required. The question is whether the space can be put to alternative uses. For instance, if it is not possible to sell the warehouse, or to rent a part of it, then there is effectively no cost associated with the available space.

When determining space cost, the organization of the warehouse should be considered. Sometimes each item is stored in a permanently designated area of the warehouse. Thus, a certain amount of space is allocated to a particular item, and this space is not used to store other items. If space is not reallocated, there is no difference in costs if the stock is there or not. In that case space cost is irrelevant.

Depreciation of materials handling equipment and facilities should not be included in the holding cost rate.

These costs are, in general, a function of time rather than of the inventory level.

Having determined total space cost, the question arises as to how this should be allocated to the various items in the inventory. From a theoretical point of view, space cost ought to be allocated in proportion to the space each item occupies in the warehouse. In other words, space cost is not related to the value of the item, but rather to its physical characteristics. Space cost typically represents only a small fraction of the total holding cost. The customary practice of regarding space cost as a fraction of the price of the item is therefore not likely to lead to grave errors in overall holding costs.

5. **Inventory Service Costs**

Inventory service cost comprises all costs associated with the value of inventory, except for the capital cost. Insurance and taxes are examples of inventory service costs. In practice, insurance and taxes are often not a function of variations in inventory levels over the year, but rather of the inventory at a given point in time. Still, the inventory level is a management decision and can be changed, so insurance and taxes are relevant as parts of the inventory service cost. Usually inventory service cost only constitutes a small part of the total holding cost, but should be included for completeness.

6. **Inventory Risk Costs**

Costs associated with spoilage, shrinkage, obsolescence, and theft are called inventory risk costs. Spoilage, shrinkage and theft depend upon the inherent characteristics of the item in terms of its attractiveness, frailty, shelf life, etc.

To a certain extent this cost category can be traded off against the space costs. Better security may lead to lower expenses in theft and spoilage. Less crowding of the

warehouse may give better stock visibility, and thus lower obsolescence cost.

Obsolescence cost is a direct function of the amount of inventory on hand, and is, together with capital cost, a major contributor to the total cost of holding inventories.

In his article "Obsolescence: the Neglected Factor", Krupp [Ref. 12: pp. 37-39] lists three types of obsolescence. These are:

1. Shelf life obsolescence, an abrupt loss of product value resulting from expiration of usable shelf life of on-hand material;

2. Technical obsolescence, an abrupt loss of product value through technological phase-out or changes in model or style superseding the previous design; and

3. Financial obsolescence, the gradual depletion of product value resulting from accrued costs incurred due to carrying a product in inventory for a prolonged period of time. (This represents the least understood and most commonly neglected type of obsolescence.)

The article describes each of these obsolescence costs in detail, and proposes a model to identify obsolete items, and the optimal strategy for disposing such.

Inventory risk cost may be expressed as a fraction of the value of the item. However, different fractions would be expected to apply to different items, depending on their unique characteristics.

7. Cost Element Listings

Several books attempt to list all the cost elements to be subsumed under the various cost categories. For instance, see Lambert [Ref. 5:p. 27] and Van DeMark [Ref 4:p. 27]. Whereas such lists may be quite comprehensive, they do not properly identify procedures for determining which of the costs vary with the inventory level. Only such costs should be included in the EOQ model. Thus, cost element listings may be helpful as a starting point, but they need to be adjusted to the uniqueness of the situation at hand.

It should be emphasized that the listing and categorization of cost elements are not aims in themselves.

In the EOQ model, only the total sum of all the holding cost elements is relevant as a parameter. Each category is of interest only to the extent it facilitates the computation of the aggregate holding cost rate.

8. The Value of Holding Cost

Van DeMark [Ref. 4:p. 150] implies that a good holding cost average in the commercial sector is 24 percent. He suggests that the normal range is about 15 to 35 percent. Lambert [Ref 5:pp. 24-25] refers to 13 studies done between 1955 and 1974 of estimated inventory carrying costs. Table 1 is extracted from Lambert's report.

TABLE 1

ESTIMATES OF INVENTORY CARRYING COSTS

Author	Publication	Estimate of Carrying Costs as a Percent of Inventory Value
L. P. Alford and John R. Bangs (Eds.)	PRODUCTION HANDBOOK (The Ronald Press Company, 1955), p. 397	25%
George W. Aljian	PURCHASING HANDBOOK (McGraw-Hill Book Company, Inc., 1958), pp. 9-29	12-34%
Dean S. Ammer	MATERIALS MANAGEMENT (Richard D. Irwin, Inc. 1962), p. 137	20-25%
Clifford M. Baumback, James D. Harty, George W. Plossl and Oliver W. Wight	MANAGEMENT OF LOT-SIZE INVENTORIES (American Production and Inventory Control Society, 1963), p. 17	15-25%
Gordon T. Crook	"Inventory Management Takes Teamwork," PURCHASING, March 26, 1962, p. 70.	25%
Thomas W. Hall	"Inventory Carrying Costs; A Case Study," MANAGEMENT ACCOUNTING, January 1974, pp. 37-39	20.4%
J. L. Heskett, N. A. Glaskowsky, Jr. and R. M. Ivie	BUSINESS LOGISTICS, Second edition (Ronald Press Company, 1973), p. 20	28.7%
John B. Holbrook	MANAGING THE MATERIALS FUNCTION (American Management Association, 1959), p. 67	24%

TABLE 1 (continued)

Author	Publication	Estimate of Carrying Costs as a Percent of Inventory Value
John F. Magee	"The Logistics of Distribution," HARVARD BUSINESS REVIEW, July-August 1960, p. 99	20-35%
Benjamin Melnitsky	MANAGEMENT OF INDUSTRIAL INVENTORY (Conover-Mast Publication, Inc., 1951), p. 115	25%
Franklin G. Moore and Ronald Jablonski	PRODUCTION CONTROL, Third Edition (McGraw-Hill Book Company, Inc., 1969) p. 376	15-25%
W. Evert Welch	SCIENTIFIC INVENTORY CONTROL (Management Publishing Corporation, 1956), p. 63	25%
Thomson M. Whitin	THE THEORY OF INVENTORY MANAGEMENT (Princeton University Press, 1957), p. 220	25%

The rate of inflation changed considerably between 1955 and 1974. However, Lambert does not address the effects of inflation. It is therefore not clear whether any adjustment has been made in the data to account for changes in the inflation rate. Still, the conclusion to be drawn from the sample in Table 1 is that no single holding cost factor is commonly accepted.

When expressing holding cost as a percentage of the price of the item, the question arises as to what price should be used as a basis for the calculation. A measure of capital cost is the profit of alternative investments foregone. Therefore, the price of the item should measure all out-of-pocket expenses incurred in order to get the material to the warehouse. This would include the cost of the item itself less any discounts. Transportation cost and

any insurance paid for the item prior to delivery should be included.

However, more important than what basis is actually used, is that consistency is maintained, i.e., that the parameters for price and the holding cost rate in the model are calculated in the same manner each time.

C. ORDERING COSTS

Ordering cost, also called set-up cost, is the sum of all costs incurred as a function of ordering items. Jannis, Poedtke and Ziegler [Ref. 3:p. 87] write:

> The variable cost of placing an order with an outside vendor include the following: the cost of preparing a material requisition and a purchase order, the time (and related costs) required to follow up a purchase order, the time and cost of receiving and inspecting, the time and costs required to place the material in the proper inventory location, and the time and costs associated with making payment to the vendor and maintaining related accounts.

Van DeMark [Ref. 4:p. 134-135] suggests the following criteria to determine if a particular cost element can be classified as a set-up cost:

1. Set-up costs are always incurred before you have the material.

2. Set up costs are fixed in size for a given order, regardless of the quantity ordered.

To determine the set-up costs, Van DeMark suggests the following formula:

$$\text{Purchasing Set-Up Cost} = \frac{\text{Inventory Control} + \text{Physical Inventory} + \text{Computer} + \text{Purchasing} + \text{Receiving} + \text{Miscellaneous}}{\text{(No. of Purchase Orders + Releases) Line Items per Order.}}$$

It should be noticed that the formula computes average ordering or set-up costs. Where several items are concerned, the method of purchasing these items is likely to vary. Factors that may cause variations include the value of annual demand of the article, relationship with the seller, and the

need to gather information about the market. Therefore, just looking at an average ordering cost may be misleading.

Correct use of the formula presupposes that only marginal costs are included. Given that the company already has a computer system, the marginal cost of processing one extra order is not likely to be very large. However, if the purchasing department is overloaded, and additional orders create the need to employ one extra person, the marginal cost is more substantial.

The magnitude of the ordering cost has a direct impact on the calculation of EOQ, and therefore on the physical inventory level. If the true ordering cost is underestimated, the result will be too frequent buying. This in turn may saturate the capacity of the ordering department with rapidly increasing ordering cost as a result.

The opposite situation is to overestimate the ordering cost. By including cost elements that do not vary with changes in the number of orders per year, the EOQ model will yield a higher inventory level and thus increased holding cost. These results may be particularly troublesome if the maximum storage capacity has been reached, because overcrowding of the warehouse is likely to result in sharply increased materials handling cost.

The purpose of the Wilson EOQ model is to minimize the sum of ordering and holding costs. A proper application of the model requires adjusting the parameters to the situation at hand.

Van DeMark emphasizes that the correct measure to use for ordering cost is the cost per line item and not the cost per order, if these are different. The cost of adding an extra line item to an existing order is probably considerably different from initiating an additional order. Actual business practice would therefore determine how marginal costs should be measured.

Even with a firm understanding of the concept of marginal costs, they may not be easy to identify, since accounting systems usually are not designed for this purpose. It may therefore be justifiable to use average cost as a substitute. This is the case if the cost of obtaining more precise data exceeds the cost associated with the imprecision.

Some elements of the ordering cost may be fairly easy to determine. When there is little idle capacity in the purchasing department, it is reasonable to apply direct labor cost. This is usually done by taking the elapsed time for the processing of an order times the wage rate for the category of personnel placing the order. Similarly, the cost of communications (telephone, postage, or electronic means of transmittal) is in most cases easy to compile.

More controversial is the question of whether to include indirect costs like supervision, office rental, and utilities. As previously pointed out, the principle is to ascertain whether an actual change in these costs will take place as a result of changing the number of orders per year.

Although theoretically correct, it is usually not feasible to determine ordering cost for increments of a single order. What is usually done is to calculate the total costs for various activity levels, and then try to fit a cost function to the observed data. The width of the relevant range depends on the unique cost structure of the organization in question.

1. Determining the Ordering Cost

The EOQ model assumes that the ordering cost is independent of the value of the order. In reality this is often not the case. Typically, authority to finalize purchases in an organization reflects a hierarchical structure. That is, orders above a certain threshold have to be approved by a higher level manager in the organization. Usually more time and effort are involved the higher the

value of the order is. In short, high value purchases tend to be more costly in terms of ordering costs than routine buys.

The degree of management intensity of the various items in stock is usually a function of the item's contribution to total sales. The so-called "Pareto's law of maldistribution" states that typically a small proportion of the total number of items accounts for the bulk of the revenues. Frequently about 20 percent of the items represent 80 percent of the total sales. This observation has led to the application of the A-B-C concept of inventory management.

Briefly, all items in inventory are ranked by sales, and the cumulative percentage of total sales and of total number of items are computed. The best selling items are classified as A items, and account for the major proportion of total sales. B items are items that generate sales in proportion to their share of the total number of items. The C items represent the majority in terms of number of items, but represent only a small share of total sales. There are several variations of this scheme. The important point however, is that management focus should be on the A items.

The ordering cost is typically a function of the contract type employed, and the business relations with the supplier. The ordering processes can vary considerably in complexity and thus incurred costs. The most inexpensive are the ones where the supplier automatically replenishes stocks at certain intervals, and the most expensive are the ones that involve extended and complicated contract negotiations. Consequently, the ordering cost parameter in the EOQ model should reflect that the actual ordering cost may vary considerably from one situation to another.

2. **Costs of Record Keeping and Physical Inventory**

Van DeMark includes record keeping and physical inventory as an ordering cost rather than a holding cost. As

this reasoning may seem counterintuitive, an explanation is in order. In his words [Ref. 4:p. 135]: "Your set-up costs should by definition (be) the cost of getting ready to have inventory." The argument is that record keeping is done in order to enable reordering at the reorder point.

An equally plausible counterargument is that record keeping is done in order to assure that deliveries can be met. Usually the warehouse receives incoming goods in large quantities, but distributes the same items in much smaller batches. Thus, the vast majority of transactions is concerned with inventory depletion and not replenishment. In other words, the inventory record keeping is a cost of selling and distributing, rather than ordering or warehousing. Therefore, the cost of record keeping and physical inventory should be treated as a holding cost, not as ordering cost.

Stockton, [Ref 2:p. 50] is of yet a different opinion. He suggests:

> The cost of a transaction reporting system is relevant when one is deciding between a fixed order quantity system and a periodic review system. However, given the decision to use a fixed order quantity system for an item, this fixed cost would be incurred regardless of the reorder level chosen.

Based on Stockton's line of reasoning, the cost of record keeping should be disregarded altogether. The view taken in this thesis is that only record keeping concerning order receipts should be included as ordering cost. The rest should be disregarded altogether as far as the EOQ model is concerned.

A similar difference of opinion exists with respect to the costs of the physical counting of inventories, and the related costs of maintaining inventory accuracy. For some reason Van DeMark regards these as set-up costs although they do not seem to fit either of his own criteria for the determination of such. On the contrary, one would expect that the costs of taking physical inventories vary more or

less directly with the amount of inventory on hand. Not only is more time needed to count a large number of items than a small one, but it is also likely to be more difficult to keep inventory discipline when the number of items in the warehouse increases. Misplaced items are more easily overlooked, and the task of reconciling inventory records to the physical inventories is likely to be more complex.

Naval Supply Center, Oakland has experienced that the process of doing inventories actually induces some errors in the records, unless all discrepancies are carefully investigated. Inaccurate records have a real cost in terms of unexpected stockouts, or higher than necessary holding cost. Consequently, it is recommended that the cost of taking an inventory be included in the holding cost and not in the ordering cost.

3. **Cost of Materials Handling**

Another interesting contradiction in the literature is found when comparing Van DeMark's and Ballou's view on materials handling on the receiving dock. Ballou claims that "...procurement costs include...the cost of any materials handling or processing of the order at the receiving dock [Ref. 7:p. 361]." Van DeMark, on the other hand, treats materials handling as "one of the prime elements" of carrying cost [Ref. 4:p. 30]. Van DeMark applies his requirement that ordering cost should be fixed in size for a given order, regardless of the size of the order. According to his reasoning this is not likely to be the case for materials handling, therefore it is not an ordering cost.

Ballou concedes that handling cost may vary to a degree with the size of the purchase, and recommends a case by case treatment of the issue. It would be expected that the cost of materials handling varies more with the number of receipts than with the size of each. There may be exceptions, but in general these costs should be treated as

part of the costs associated with ordering a shipment of material.

4. Quantity Discounts

The Wilson EOQ formula supposes that the purchase price for an item is fixed and independent of ordering quantity. In reality this is often not the case. The practice of offering quantity discounts is widespread. Also, the use of truckload versus less than truckload transportation may cause discontinuities in the price parameter of the model since the holding cost rate usually refers to the purchase price f.o.b. destination.

Quantity discounts usually take two basic forms. One alternative is to have a series of price breaks, and to apply the discount to all items if a sufficiently large quantity is bought. The other alternative is that the quantity discount only applies to the quantity in excess of the price break.

The way to handle the first alternative is to apply the EOQ model heuristically. Tersine [Ref. 1:p. 104] describes the following procedure: Start with the lowest possible price and compute the EOQ. If this quantity is within the range where the discount is applicable, the optimal solution is found. If the quantity is not valid, apply the next higher price. Repeat the process until a valid quantity is found. Then compute the total costs including the cost of the items for the EOQ and for all larger price-break quantities (using a Q equal to the price break quantity). Select the least cost alternative.

The second alternative is slightly more complex and will not be covered here. Interested readers are referred to Hadley and Whitin, Analysis of Inventory Systems. [Ref. 9]

Quantity discounts reflect benefits to the seller of handling larger quantities. The seller incurs certain fixed costs in processing an order, regardless of the size. Larger orders mean that the seller incurs these costs fewer times.

The resulting savings are then partially passed over to the customer. In many cases, the seller does not formally offer quantity discounts. However, the price may be negotiable to a certain extent depending on the quantity.

A special variation of quantity discounts is the case of bid solicitations. This is a common practice in public procurement. The buyer announces the intention to purchase a predetermined quantity of material, and awards the contract to the lowest price bidder. If this quantity is set without regard to economic lot sizes, there is a probability that a better deal could have been struck if the quantity had been increased. If the bidders' production costs were known to the buyer for various quantities, economies of scale might be attained for both parties.

An indirect attempt to capture some of the benefits of increasing the order quantity could be to impose a higher ordering cost. This would force the EOQ model to suggest larger optimal buy quantities, and thus, could result in economies of scale to the producer. In a competitive environment, or where the size of the order is large relative to the suppliers production capacity, some of these economies of scale would presumably be passed over to the buyer.

5. **Some Concluding Comments**

This chapter started with a description of the Wilson EOQ model, and the underlying assumptions for using it. It was pointed out that the model is fairly insensitive to small errors in the individual parameters. However, any error in the parameters of the model will lead to less than optimal performance in terms of total variable cost. In determining the correct parameter settings, opportunity cost should be recognized as a relevant cost.

Section B discussed each of the elements of holding cost; capital cost, space cost, inventory risk cost and inventory service cost. There is no one correct holding cost

rate to be found in the literature, thus, the proper rate has to be estimated on a case by case basis. Although different concepts of capital cost may be employed, it was concluded that the rate of inflation should not be a part thereof.

The last section of this chapter presented some differing views on what should be included in the ordering cost. The effect of quantity discounts on the calculation of EOQ was briefly addressed. This chapter has presented a general theory around the EOQ model. In the next chapter the application of this model in a military environment is discussed.

III. BACKGROUND

The preceding chapter presented a general discussion of points to consider when trying to determine the correct magnitude of holding and ordering costs. As repeatedly pointed out, a major problem is to determine whether a particular cost element would have a marginal impact on the total costs.

This chapter will discuss how the framework described in Chapter II relates to present policies for managing consumable items at Ships Parts Control Center. The first section describes the environment in which SPCC operates, and SPCC's role in the supply system in the US Navy. External and internal constraints on SPCC's use of EOQ models in its operations are addressed. Section B describes purchase types and procedures, whereas section C discusses the calculation of the holding cost and the economic order quantity at SPCC.

A. SHIPS PARTS CONTROL CENTER AND THE NAVY SUPPLY SYSTEM

This section is primarily based on NAVSUP Publication 553 "Inventory Management" [Ref. 13]. The Naval Supply Systems Command (NAVSUP) is responsible for issuing policy direction and guidance in the broad area of inventory management within the Navy. These are general managerial responsibilities. The major commands which execute the Navy supply management functions are; The Aviation Supply Office (ASO), the Ships Parts Control Center (SPCC), the Publications and Form Center, the Fleet Material Support Office (FMSO) and the retail intermediate stock points.

ASO and SPCC are inventory control points (ICPs) and manage about 27 percent of the near two and a half million line items that are cataloged in the Navy Supply System. These are primarily items that are unique to the Navy. The rest are items that are of common use among the services.

These common items are managed by the Defense Logistics Agency and the General Services Administration.

SPCC employs about 200 item managers who control 550,000 line items worth some $6.6 billion. On average, about 3200 requisitions are processed daily, resulting in the expenditure of nearly $4 million per day.

In order to manage this formidable task, item managers have access to a computer system known as the Uniform Inventory Control Programs (UICP). UICP was developed in the mid 1960s and incorporates mathematical models to forecast demand, and to compute wholesale[2] inventory levels for peacetime needs. Two other levels of inventories are the retail intermediate and the retail consumer. These levels will not be considered in this thesis.

The definition of wholesale inventory describes some of the functions of an inventory manager. Examples of asset control include requirements determination, material distribution and procurement of replenishment stock, repairables management, and disposal.

The Inventory Control Points typically do not store wholesale inventories. This is the function of the stock points, of which there are 43 located throughout the world.

The stock points are responsible for the physical handling of the material; receiving, stowing, issuing, and shipping. Receiving and shipping are reported daily to the ICPs where overall visibility of stocks is maintained.

The stock points also have other administrative responsibilities like budgeting and accounting for funds to procure material, and billing the customers.

---

[2]An inventory, regardless of funding source, over which the inventory manager has asset visibility at the national level and exercises unrestricted asset control to meet worldwide inventory management responsibilities.

Fleet Material Support Office is tasked with the responsibility of providing and maintaining the computer programs necessary to allow the hardware to operate. Among these programs is the UICP.

The formulae to compute inventory levels and reorder quantities in UICP are based on inventory models described by Hadley and Whitin in their book Analysis of Inventory Systems which was published in 1963 [Ref. 9]. These formulae are somewhat more complex than the one presented in Chapter II of this thesis, as they include shortage cost and relative military essentiality as parameters. The inclusion of shortage cost and essentiality factors adds flexibility to the model, since these parameters can be used as management tools to enforce desired inventory policies. Assigning a high essentiality (worth) to an item will increase its inventory level by recommending a higher reorder point. Thus, higher protection against stockout is obtained.

The shortage parameter is indeed sometimes used as a knob to adjust EOQ computations to desired levels. Consequently, SPCC's models are less sensitive to changes in the parameters for holding and ordering costs than the original EOQ.

UICP generates purchase requests (PRs) based on the assumptions in the model. Item managers may choose to override these recommendations if they feel that circumstances have changed sufficiently to make the model's assumptions unrealistic.

1. Constraints on EOQ Calculations

Inventory management in the military is not aimed at maximizing some profit function, as is usually the case in the commercial sector. Instead, the goal is to provide maximum supply support to the operational (fighting) units within available financial resources.

The objective of maximizing supply support subject to limited resources may not be compatible with uncritically

applying the EOQ model to all items. In general, the EOQ model should not be used for items where demand forecasts are highly unreliable, as the model assumes that the demand rate is known, or can be reasonably estimated by some probability distribution. Nor should the EOQ model be used for items with a very low annual demand. This would violate the assumption of being able to approximate the demand rate by a continuous function.

The majority of items at SPCC has very little or no anticipated demand. A large number of so-called non-demand based items are therefore managed based on criteria other than the minimization of total variable costs.

2. Non-Demand Based Items

NAVSUP Publication 553 [Ref. 13:p. 2-37] defines Non-Demand Based Items as:

> ...any items for which the Cost Difference (COSDIF) equation indicates it is more costly to stock than not to stock. There are two types of non-demand based items, insurance items and numeric stockage objective (NSO)items.
>
> An insurance item is an essential item for which no failure is predicted through normal usage, but if a failure is experienced or loss occurs through accident, abnormal equipment/system failure or other expected occurrences, lack of replacement would seriously hamper the operational capability of a weapon or weapon system. An NSO item is an essential item for which the probability of demand is so low that it does not meet the demand based stockage criteria. Since the lack of a replacement item would seriously hamper the operational capability of a weapon or weapon system the item is therefore stocked but as non-demand based.

Items can be included in the NSO category for other reasons as well. The policy is further described in NAVMAT Instruction 4423.8 [Ref. 14].

3. Planned Program Requirements

Ideally, the demand parameter in the EOQ model should reflect a situation where items are withdrawn from inventory one at the time. Yet, demand should occur so frequently that its pattern could be approximated by a continuous function without a significant loss of accuracy. In many instances these criteria are not met. Rather than being random, some

demand in the Navy is derived from specific projects of a non-recurring or recurring nature. Demand generated in this manner is referred to as planned program requirements (PPRs). To use non-recurring demand data in the EOQ model would violate the underlying assumptions. PPRs must therefore be identified, and determinations must be made whether to include them in total demand, or to treat them separately.

4. Provisioning

The collection of items managed by an inventory manager is changing over time. Old systems are phased out or replaced. Ideally, during this process all spare parts and repair parts that are used exclusively in these systems are disposed of, and removed from the data files. At the same time, new and frequently more sophisticated systems take their place. The process of introducing new items into the supply system is called provisioning.

Despite all efforts to foresee demand for spare and repair parts for new systems, forecasts are subject to considerable uncertainty. For this reason, EOQ calculations are not used in the provisioning process until sufficient demand history has been accumulated to provide stable forecasts.

5. Regulatory Constraints

DoD Instruction 4140.39 [Ref. 15] states that "a minimum procurement cycle of three months demand and a maximum procurement cycle of three years demand will normally be used." The minimum limit is set so as not to overload the purchasing departments, and the maximum limit is set to avoid excessive inventories, should demand for some reason be less than anticipated.

In a study of the inventory management in the US Air Force it was noted that [Ref. 16]:

> The effect of such artificial constraints is to increase the holding costs for high value items with a rapid turnover and to increase the ordering costs on low value items with infrequent demand. The upper constraint

may also limit order quantities to the extent that the full potential benefits from quantity discounts cannot be reaped.

6. Financial Constraints

The great majority of a ship's consumables (items in cognizance group 1H) are financed through the Navy Stock Fund (NSF). NSF is a revolving, working capital fund which consists of physical assets (items) and cash. Items are bought by the stock fund, and later sold to user activities for cash. The price charged includes a surcharge which is meant to cover all costs of the stock fund's operations. The need to convert assets to cash for financing of new purchases may curtail the size of the order quantity of an item. This may happen even if EOQ calculations indicate that larger quantities are more economical. These are tradeoffs that have to be taken into consideration in connection with the budget process.

7. Computational Constraints

Personnel in the operations analysis division at SPCC [Ref. 17] are concerned that UICP is generating too small economic order quantities. The recommended quantities are often too small to be obtainable from the industry. Further, SPCC's capacity to handle purchase requests is limited. There is presently a large backlog of PRs at SPCC, and administrative lead time is somewhere between 270 and 330 days. A study in 1985 indicated that close to 80,000 purchase requests were in the procurement pipeline at any given time. This number was estimated to be fairly representative of the present situation, although a program to reduce the backlog by 24 percent, over a three year period starting from 1987, has been undertaken.

Aiming at decreasing the number of PRs generated, some constraints have been imposed on the EOQ calculations. In 1984 the minimum order quantity was set at four quarters of anticipated demand. In 1987, a flexible lower bound was

introduced. An internal study at SPCC [Ref. 18] revealed that out of some 550,000 line items, only about 100,000 had an average quarterly demand higher than .25 during the last two years. Of these, about 87,000 were non-provisioning, non-program related items. From this sample, 25,000 line items were identified, and constrained in terms of their EOQ calculations. For 16,250 line items, the minimum order quantity was set at ten quarters of forecasted attrition demand. These were items with a value of annual demand less than $4,000. 6,250 line items with a value of annual demand between $4,000 and $25,000 were constrained to a minimum of eight quarters of demand. The remaining 2500 items were constrained to four quarters of demand. The value of annual demand for this category exceeded $25,000. By restricting the policy to low value of annual demand items, the potential risk of ending up with too much stock on hand is minimized.

For other items the minimum quantity was reduced from four to three quarters of demand. These policy changes were expected to reduce the number of PRs per year by more than 6,000.

Finally, it should be mentioned that the item manager may choose to override the model's EOQ quantity. The extent and effects of such actions are not known.

8. Policy

The primary policy document on inventory management of secondary items in the Armed Forces is Department of Defense Instruction 4140.39, Procurement Cycles and Safety Levels of Supply for Secondary Items [Ref. 15]. The instruction states the following objective for the inventory management policy: "To minimize the total of variable order and holding costs subject to a constraint on time-weighted, essentiality-weighted requisitions short."

The total variable cost (TVC) for the inventory is expressed as the sum of ordering cost, holding cost and an

implied cost of time weighted shortages. Implied shortage cost is used because the true value of this cost is unknown.

The Instruction uses the following definitions:

> Variable Cost to Order. Those costs associated with the determination of requirements, processing of purchase requests, and subsequent contract actions through receipt of the order into the ICP system that will vary significantly in relation to the number of orders processed. Costs are considered "fixed" if they would remain constant should 50 percent of the workload be eliminated.
>
> Variable Cost to Hold. Those costs associated with the cost of capital, inventory losses, obsolescence, storage, and other variable costs of maintaining an inventory. The 50 percent rule relative to variability applied to variable cost to order should also be applied here.

Enclosure three of the instruction describes the procedure to determine the cost to order an item of inventory at an ICP. The instruction states that:

> The cost to order an item of inventory to be used in the determination of annual variable Order Cost (OC) will be dependent on the type of procurement method to be used in placing the requirement on order.

Attached to enclosure three of the DoD Instruction is a detailed listing of functional elements to be included in cost to order at the inventory Control Point (ICP) level. A copy of this list is shown in Appendix A. The DoD Instruction specifies that: "Only those costs which are variable as a function of the number of orders placed are to be considered."

B. PURCHASE TYPES AND PROCEDURES

DoD Instruction 4140.39 specifies that three basic costs to order will be developed to cover the different types of procurement.

1. Small purchases, i.e., purchases with a value of less than $2,500.
2. Purchases utilizing a call-type contract, and
3. Purchases where the contract value is greater than $2,500 (large purchases).

The instruction allows further breakdown of procurement type when warranted. The threshold values for small

purchases has been increased several times. The last time was in 1982 when it was increased from $10,000 to $25,000.

At SPCC four different cost to order values have been calculated since 1976, depending on the type of buy. The alternatives are: purchase orders, delivery orders, negotiated contracts and advertised contracts.

1. **Purchase Orders**

Purchase orders are used for small purchases. Potential suppliers are contacted in writing, and are invited to deliver a specified quantity of a product. This request is not binding for either of the parties. A contract results if the supplier responds with an offer that is subsequently accepted by SPCC.

2. **Delivery Orders**

Delivery orders are a call type contract, meaning that one contract covers a number of buys. Price and delivery conditions are covered in the contract. Usually, a minimum or a maximum quantity is stipulated. The contract is let competitively. It covers a fixed period of time, usually one year. The supplier is bound by the contract to make deliveries as requested, and in accordance with the terms of the contract.

A delivery order is a contract vehicle well suited for items with a recurring demand, and with easily defined characteristics. Delivery orders can only be used for small purchases.

3. **Negotiated Contracts**

Negotiated contracts are used for large purchases. Price, delivery conditions and item characteristics are all subject to negotiation. Negotiations may take place with a single supplier or with a number of potential suppliers.

4. **Advertised Contracts**

Advertised contracts are used for large purchases. No negotiating takes place for advertised contracts. All

item characteristics and delivery conditions are specified in a solicitation for bids. The procedure for advertising and for the award of contracts follows strict rules, as described in the Federal Acquisition Regulation (FAR). Only responsive and responsible bidders are considered. The criterion for awarding an advertised contract is lowest price.

Large purchases are much more complex and time consuming than small ones. At SPCC, the cost to order parameter for large purchases is approximately three times as high as for small purchases. Only about 10 percent of all purchase actions at SPCC fall in the large purchases category. But, in terms of dollar value, they represent about 90 percent of the procurement costs.

5. Cost to Order Computations

SPCC annually computes the administrative cost to order for each type of purchase. The results are used as parameters in the EOQ calculations, and in turn for the calculations of budget requirements.

The threshold value of buy that determines what ordering cost to use in UICP is not $25,000, as might have been expected since $25,000 is the value that determines whether a buy falls into the small or large purchases category. Instead, a value of $8,000 per order has been kept as the break point, as was the case before 1982. The decision not to raise the break point value seemed to be based on a feeling that too many low value purchase requests were generated. The result of the decision is that the cost to order parameter for large purchases is applied to buys worth between $8,000 and $25,000. This reduces the frequency of buys for items in this value category compared to what would have been the case had the parameter for small purchases been used.

The process of identifying the cost to order parameter for the various types of buy is an annual process.

Data for total variable ordering cost for the first three quarters of the fiscal year are gathered from various sources. The number of line items acquired through the various types of buy are estimated for the same time period. These data are annualized, and then adjusted for expected changes in prices and activities for the upcoming fiscal year. In determining what cost elements to include in total cost, the guidance in DoD Instruction 4140.39 is followed as closely as the availability of data allows.

Cost elements that are particular to one type of purchase are identified. The cost per line item for the various types of buy is then found by dividing total cost by the number of line items in each category. An example of the format for collecting source data, and a further explanation on how data are collected, is included as Appendix B.

In addition to the costs incurred at SPCC, some external costs are included. The magnitude of these external costs is directed by NAVSUP. External costs are incurred as a result of the physical storage and handling that takes place at the storage locations. As previously mentioned, these are located separately from SPCC.

6. Quantity Discounts

SPCC has included a manufacturing set-up cost of $150 in the calculation of administrative ordering cost since 1985. The amount is supposed to reflect manufacturers' cost of producing and delivering an order. No documentation was found as to how the amount of $150 originally was determined. But according to personnel at SPCC [Ref. 19], the amount was supposed to reflect the relationship between quantity discounts and price break quantities for a number of items. Thus, the purpose is indirectly to capture a discount for larger purchase quantities.

Until recently, other attempts to calculate economic order quantities with respect to quantity discounts, have not

been made at SPCC. One reason has been hardware and software constraints in the UICP. A process to remedy this situation is underway in a two-phased project called resystemization and resolicitation. New hardware has been acquired, and several of the programs that have been in use since the 1960s are completely rewritten.

SPCC has long felt the need to be able to evaluate quantity discounts in a systematic manner. A program called Q-Star (Q^*) was therefore developed for an IBM-PC. A prototype presently covers approximately 2000 different line items, and will soon be expanded to cover some additional 8000. Q^* will in addition to handling price break quantities, take procurement lead time into account in an attempt to identify an improved purchasing strategy.

C. HOLDING COSTS AND THE ECONOMIC ORDER QUANTITY

Enclosure four of DoD Instruction 4140.39 outlines the development of the holding cost. Four elements are mentioned; investment cost, storage cost, obsolescence cost and other losses. These elements correspond well to the categories of capital cost, space cost and inventory risk cost as described in Chapter II. Since no taxes or insurance are paid on government inventories, the inventory service cost category is not applicable.

1. Investment Cost

The way capital cost is calculated in the public sector differs from the customary calculations in the commercial one. The government is not a business entity, and is not trying to maximize profit. Therefore, none of the concepts for valuing capital cost discussed in Chapter II apply directly.

DoD Instruction 4140.39 states that: "The view taken towards the investment of funds in inventory is that each public dollar so invested represents a dollar of investment in the private sector thus foregone." Based on this

reasoning a 10 percent cost of capital per year (discount factor) is chosen by DoD. The directive states further that: "Since most order quantity decisions are of a relatively short-range nature, this cost need not be discounted."

The Instruction was issued in 1970 and the value of capital cost has remained unchanged since then. The value of 10 percent per year is consistent with Circular No. A-94 of the Office of Management and Budget (1972) [Ref. 20:p. 4] which decrees the following:

> The discount rates to be used for evaluations of programs and projects subject to the guidance of this Circular are as follows:
>
> a. a rate of 10 percent; and, where relevant,
> b. any other rate prescribed by or pursuant to law, Executive order, or other relevant Circulars.
>
> The prescribed discount rate of 10 percent represents an estimate of the average return on private investments, before taxes and after inflation.

The principle for determining the cost of capital is to set the cost equal to the average rate of return in the commercial sector. The rationale is that this will lead to an optimal resource allocation between the public and the private sector.

Sassone & Schaffer [Ref. 21:pp. 99-129] present a number of different views about the proper discount rate to use in public enterprises. Among the concepts discussed are those of the market interest rate, the marginal productivity of investment, the corporate discount rate, the government borrowing rate, the Pigouvian rate and the social opportunity cost of capital. The conclusion is that there is little consensus as to what should be the proper rate to use.

DoD Instruction 4140.39 and OMB Circular No. A-94 implicitly assume that money for investment in the public sector is raised entirely through taxation. In reality, a large part of public financing takes the form of issuance of Treasury bills and bonds. The rate of return on such securities presently runs at nine to ten percent annually.

Adjusting for an estimated rate of inflation of four to five percent, the real rate of return before taxes and after inflation is at best in the vicinity of five percent annually, and probably even lower. Brigham & Gapenski write [Ref. 11:p. 197]:

> The real rate on short-term goverment securities, which is also the pure rate of return, has historically ranged from 2 to 4 percent, with a mean of about 3 percent. Thus, if no inflation were expected, risk-free government bills would yield about 3 percent.

The fact that some investors are willing to accept a real rate of return of about three percent, means that their hurdle rate is even lower. This does not necessarily indicate that the average return on investments in the private sector is of this magnitude. But the point is, the government is in fact able to raise capital at a cost considerably below the ten percent stated in the circular. Therefore, to use a discount factor based on the average return on private investments, is a political rather than an economical decision. The mandated value of 10 percent is likely to considerably overstate the true capital cost associated with holding inventories.

2. Storage Cost

DoD Instruction 4140.39 cites previous studies by "the Military Departments" and the "Defense Supply Agency" to the effect that the storage cost rate at most is in the vicinity of one percent. Further, the instruction states that this is such a small fraction of the total holding cost that further studies to refine this estimate seem to be unwarranted. The one percent holding cost rate has been applied unchanged since the issuance of the instruction (1970). In an interview at Naval Supply Center Oakland, personnel from the inventory management department indicated that there was no reason to believe that the storage costs exceed one percent of the inventory value [Ref. 22]. However, exact figures were not available.

The one percent storage cost rate is lower than the typical corresponding value in the private sector. A possible explanation of this, is that the Government does not incur such inventory service costs as taxes and insurance. The instruction includes amortization of storage facilities in the one percent figure, although most of the literature in the field suggests that this cost should not be considered. On the other hand, the instruction omits the cost associated with alternative uses of the facilities.

The government is not a business entity. One may therefore argue that the concept of opportunity cost does not apply in the public sector. However, if one disagrees with that argument, the storage cost rate of one percent annually may turn out to be too low.

a. Opportunity Cost

Potential revenues from leasing government property would traditionally go to the Treasury, and not to the cognizant department. Consequently, there has been little or no incentive to include any opportunity cost associated with owning property and warehouses. Due to some recent changes in legislation, a different approach may be taken in the future.

The background is that NSC Oakland, California has been approached by the Port of Oakland about leasing part of NSC's area to build a modern container terminal. This terminal would be operated by the Port of Oakland. However, if a crisis should occur, the Navy would resume full control.

The tentative agreement includes a 25 year lease with an option for renewal. The revenues, estimated at more than 25 million dollars, will go directly to NSC Oakland. The agreement is not finalized, but it could have some interesting ramifications for the estimated costs of storing material. If the tentative agreement sets a precedence, it would mean that the opportunity cost concept should be

applied to the estimation of storage cost at Navy facilities. This in turn would increase the space costs to a level more comparable to those used in the commercial sector.

3. Inventory Risk Costs

DoD Instruction 4140.39 distinguishes between two types of inventory risk costs, "obsolescence" and "other losses". The instruction states that the obsolescence rate is to be computed by dividing the value of material transferred for disposal in a year, by the average value of material on hand during the preceding year. At least five years of data are to be kept to allow a smoothed rate to be established. According to the instruction, separate obsolescence rate calculations for separate commodity groupings are authorized "... where warranted by the nature of the materiel." This option has not been used. SPCC has used the same obsolescence rate for all consumable items since the instruction was issued.

Two problems are inherent to the way of calculating the obsolescence cost rate as described in DoD Instruction 4140.39. The first is to assure that obsolete material is correctly identified and disposed of. The second problem is to assure that the values in the computation are determined in a consistent manner.

4. Disposal Policy

From 1984 there has been a de facto moratorium on disposal actions in the supply system. NAVSUP announced its policy on disposal actions through a series of messages to all Navy activities. The policy basically states that all serviceable material, with or without a weapon system application, be retained. The policy specifically addresses a few situations where disposal of material is allowed. However, the emphasis is on retaining items within the Navy Stock Fund.

Potentially obsolete items are identified through a subroutine of the stratification software used twice a year in UICP. Material is regarded as obsolete if there is no anticipated use for the item, or if items on hand exceed any foreseen demand. Whether any actual disposal takes place depends on whether the item may be needed by other services, or can be sold by Foreign Military Sales. The value of items classified as potential/disposable excess more than doubled between 1984 and 1988. According to recent computations, the value is now approximately $3.3 billion [Ref. 23].

The value of NSF financed items that were actually disposed of in 1987 was $146 million. However, this figure cannot be used to compute the obsolescence rate, as it does not reflect the value of all obsolete items. Further, there are no ways of distinguishing between disposal actions due to obsolescence and due to other reasons, e.g., items damaged beyond repair. An attempt to verify the actual obsolescence rate, by performing the calculation described in DoD Instruction 4140.39, has therefore not been possible.

Because of the reluctance to dispose of items, considerable crowding has taken place at Navy stock points. As of 30 June 86 a total of 91.3 percent of the floor space was occupied, and 98 percent was obligated occupied at the 10 largest NAVSUP activities [Ref. 24]. One can surmise that such a high space utilization is slowing down the response time at the stock points. A change in policy towards more active disposing of excess material is therefore expected shortly.

Inactive items may be relatively straightforward to identify as obsolete. The real problem arises when trying to determine whether excessive amounts of an item are being kept in stock. In that case, a disposal decision must be made. The dilemma is expressed in a FMSO report entitled "An

Economic Retention Model for Excess Navy Material" [Ref. 25:p. 6].

> Excess material should be held only where economic criteria indicate that the costs of reprocurement at some future time will exceed the costs to hold the material. Holding costs include the opportunity cost of not liquidating the assets through disposal, repair costs, and physical storage costs. Material should be disposed if:
>
> Proceeds for disposal + repair costs + storage costs > reprocurement costs

Without going into the mathematics of the model, a few general comments are warranted. Proceeds from disposal go to the U. S. Treasury. For all intent and purposes the disposal value to the Navy is zero. To the Navy, the major motive for disposing of material is therefore to avoid future holding costs.

5. **Computation of the Obsolescence Rate**

As previously pointed out, there are problems with following the method to calculate the obsolescence described in DoD Instruction 4140.39. The lack of reliable data has been addressed. However, even if reliable data had been available, the stated method may lead to misleading conclusions about the true obsolescence rate. The reason is that items in general are disposed of many years after they were last purchased. During the intermittent time period, the inventory value may have changed considerably, due to changes in the inventory level. The obsolescence rate might have been computed in physical rather than in monetary terms. It can therefore be appreciated that changes in the inventory level would distort the computations. From a theoretical point of view, the value of disposed items should be compared to the average value of inventory at the time of purchase, not at the time of disposal. This way, distortion of data due to changes in inventory levels could be avoided.

6. **Life Expectancy of Items**

In practice, the method used at NAVSUP to determine the obsolescence rate differs from the guidance in DoD

Instruction 4140.39. The reason is that the available data are of insufficient quality to support the calculations necessary to comply with the instruction.

The method actually used is to regard the obsolescence rate as the inverse of the estimated number of years of useful life for the item. A consumable item is expected to have a useful life of eight and a third years. Thus, an obsolescence rate of 12 percent is computed. This rate covers other losses as well, and is therefore equivalent to the sum of 10 percent obsolescence and two percent other losses. These are the values given in NAVSUP publication 553.

The idea behind NAVSUP's way of computing the obsolescence rate is to express it as the probability that an item will become instantaneously obsolete in any given year. This probability is assumed to be uniformly distributed, and to be independent from year to year. These assumptions make it possible to avoid the difficulties of trying to estimate at what point in time the item will become obsolete. However, the realism of a uniform distribution can be questioned. A more probable assumption might be that the chances of an item becoming obsolete are an increasing function of time from the point of introduction into the supply system. Therefore, some other function might more accurately describe the probability of an item becoming instantaneously obsolete.

There are many reasons why items become obsolete. When weapons systems are replaced, or upgraded, there is no longer any need to stock spare parts used exclusively for that particular system. Thus, any spare part left in inventory becomes instantaneously obsolete. The aim is therefore to have as few spare parts left in inventory as possible when the demand suddenly drops.

A potential way of reducing the risk of ending up with an excess supply of some spare part would be to use an increasing holding cost rate over time. One possibility is to let the applied holding cost rate increase over time in inverse relationship to the expected remaining useful life of the item. This would have the effect of gradually reducing the EOQ as the item itself, or the system it was supporting, got closer to the end of its useful life. The problem would be to determine the total life time of the system, and keep track of its expected remaining life. This problem would be even more complex for parts used in many different systems, because these would have an ever changing mix of ages. On the other hand, the risk of ending up with excess supply would be expected to be correspondingly less if demand stemmed from many different sources. Further research would be needed to assess the feasibility of using an increasing holding cost rate over time.

Another unrealistic, but implicit assumption in the way the obsolescence rate is presently set, is that all items have the same life expectancy. Apparently no studies have been done at SPCC or at NAVSUP to suggest a variable rate for obsolescence based on the inherent item characteristics.

It was stressed in Chapter II of this thesis that inaccurate estimates of any of the parameters in the EOQ model would lead to higher than necessary TVC. This is true whether the parameter is underestimated or overestimated. Consequently, using a parameter that on average is correct for a number of items will <u>not</u> give the lowest possible aggregate TVC for all of the items. The practice of using some average value for any of the parameters in the EOQ model may still be justifiable, but only should the costs of obtaining and using more exact parameters exceed the benefits of increased accuracy.

7. **Summary**

Section A of this chapter described SPCC and the Navy supply system. It was pointed out that the basis for inventory management at SPCC is an EOQ model, although a number of constraints are imposed on the model, and it is not applied to all items. Section B described four types of contract vehicles: purchase orders, delivery orders, negotiated contracts, and advertised contracts. Section C discussed investment cost, storage cost, obsolescence cost, and other losses with respect to DoD Instruction 4140.39. The way obsolescence cost and other losses actually are computed was found to differ from the instruction.

Finally, two ways of applying differentiated obsolescence rates to various items were discussed. One possibility is to use an increasing obsolescence rate over time. Another possibility is to apply various rates, depending on the expected life time of the item. Using a single holding cost rate for several items is not optimal, even if the applied rate represents a true average of the holding cost for each individual item. This point will be further discussed in the Chapters IV and V. The next chapter will also present the methodology and the data for computing the applied ordering cost at SPCC.

IV. METHODOLOGY

In Chapter III, SPCC's role in the supply system of the US Navy was described. The extent to which the EOQ model is actually used was discussed. This chapter will present the data and the methodology for estimating the parameters for ordering and holding costs. Linear regression analysis is performed on the ordering cost data, whereas a simulation model is used to analyze changes in TVC resulting from various holding cost rates.

A. PRESENTATION OF DATA

1. Ordering Costs

Ordering cost parameters for four different purchasing types have been computed at SPCC every year since 1976, except 1977 and 1984. In 1986 the parameters were computed as usual, but not implemented in the EOQ model. Instead the parameters for the previous year were used.

All the cost elements included in SPCC's calculations seemed to be relevant for determining the administrative cost to order. Similarly, it appeared that no major cost element was omitted. However, whether the amount allocated to each cost element was correctly computed was not evaluated. A copy of SPCC's background material for determining costs to order for 1989 is included as Appendix B.

2. Workload

DoD Instruction 4140.39 states that costs are considered fixed if they "...would remain constant should 50 percent of the workload be eliminated." The instruction does not use the term marginal cost, but states that "...only those costs which are variable as a function of orders placed are to be considered."

No definition of workload is given in the instruction, but is in this thesis taken to mean the number

of purchase actions per year. A synonym for purchase actions which is used in the source data, and in this thesis, is the number of "line items" purchased. The data in Table 2 were compiled at SPCC by counting the number of contracts and then multiplying by an average number of line items per contract. Consequently, unique items (as identified by National Identification Number (NIN)) count as one line item each time they are ordered.

Prior to 1976, no differentiation was made between negotiated and advertised contracts. Further, available data are rather sparse for this period. Therefore, the analysis is confined to the period 1976 - 1988.

Table 2 shows the projected cost to order parameters (A_T) as calculated by SPCC. These are calculated based on SPCC's total variable ordering cost. The years refer to the fiscal years which were the basis for the calculations. Ordering cost parameters actually implemented for the succeeding fiscal year, differ from the values in Table 2 only in rounding.

TABLE 2

PROJECTED COSTS TO ORDER FOR VARIOUS TYPES OF BUYS

Fiscal years	Purchase orders	Delivery orders	Negotiated contracts	Advertised contracts	Added costs[3]
1976	104.25	100.40	275.19	325.53	
1977	Data not	available			
1978	158.33	153.21	445.51	503.92	
1979	158.38	153.43	398.31	453.62	29.34
1980	145.60	135.76	434.16	468.36	32.01
1981	148.24	135.10	527.75	564.32	33.55
1982	174.26	162.84	530.24	561.02	38.83
1983	233.05	220.22	923.81	958.37	40.38
1984	Data not	available			
1985	660.21	643.56	1932.26	1970.65	191.79
1986	716.97	701.38	1853.42	1875.17	191.79
1987	653.58	631.80	2026.65	1701.22	193.91
1988	729.36	700.77	1820.48	1729.10	196.14

The data in Table 2 are compiled based on SPCC's best estimates for the total variable costs and the number of

[3]These costs are external to SPCC's operations. $150 are included as manufacturers implied set-up costs from 1985. This practice was discussed in Chapter III of this thesis.

purchase actions in each category. Table 3 summarizes the number of line items purchased under various methods.

TABLE 3

NUMBER OF LINE ITEMS PURCHASED UNDER VARIOUS METHODS

Fiscal year[4]	Purchase orders	Delivery orders	Negotiated contracts		Advertised contracts
1976	98012	77720	14408	4792	1132
1977	Data not available				
1978	98136	*	*	*	*
1979	102648	*	*	*	*
1980	114160	*	*	*	*
1981	125288	85344	32904	6316	724
1982	113392	72876	33732	6064	760
1983	104271	68334	31616	3461	860
1984	Data not available				
1985	54112	41515	8987	2949	661
1986	50574	36127	9969	4027	391
1987	50634	36190	9953	4293	198
1988	55195	38102	10976	5940	177

NOTE:
* Data not available

Unfortunately data for 1984 are not available. This omission should be noted since a significant drop in the number of line items purchased took place between 1983 and 1985. Several persons at SPCC, including the one who actually compiled these data, were interviewed about potential causes for this drop [Ref. 26]. Various theories were offered, but no definite conclusion was reached.

There are at least two ways of interpreting the drop in purchase actions. One possibility is that the number of buys was reduced according to a management decision. As it turned out, the minimum order quantity was increased from 1 to 4 quarters of demand in 1984. This decision forced a decline in the number of purchase actions, but whether this is the sole explanation is uncertain. There is also a possibility that some external factor, such as changes in the Federal Acquisition Regulation, made each purchase action

[4]All values for the years 1976 - 1982 (inclusive) are multiplied by four to make them comparable with the rest. The reason is that the values in this period were calculated based only on data from the third quarter of the base year.

increasingly complex, and thereby reduced the productivity of the contracting department.

The Competition in Contracting Act (CICA) was passed by Congress in 1984. This law changed the preferred method of contracting from advertised contract or "sealed bid" as it was called at the time, to full and open competition, i.e., negotiated contracts. Data from subsequent years indicate that the use of advertised contracts has continued to decline, whereas the number of negotiated contracts has increased since 1985. This, however, does not explain the abrupt drop in small purchases actions.

According to the people interviewed at SPCC, no changes in the routine for calculating total variable costs between 1983 and 1985 could explain the behavior of the data as presented in Table 3.

3. Total Ordering Cost

A summary of the source data used to calculate the ordering cost parameters by SPCC is presented in Table 4. The columns represent year, total labor costs, total ADP costs (as they relate to the reorder function), total miscellaneous cost, and the total sum. Appendix B of this thesis contains a detailed description of how each category is calculated.

TABLE 4

TOTAL VARIABLE COSTS - CURRENT YEAR DOLLARS

Year	Labor	ADP	Misc.	Total
1976	9,967,652	545,616	636,944	11,150,212
1977	Data not available			
1978	11,719,120	696,480	1,061,176	13,476,776
1979	12,311,784	742,632	966,532	14,020,948
1980	12,376,704	777,304	713,396	13,867,404
1981	13,974,016	1,210,516	783,332	15,967,864
1982	15,672,456	369,440	758,444	16,800,340
1983	19,307,132	1,003,356	898,096	21,208,584
1984	Data not available			
1985	27,678,322	1,191,508	1,363,725	30,233,555
1986	29,470,747	1,004,173	927,751	31,402,671
1987	25,328,793	1,320,661	1,750,609	28,400,063
1988	30,465,855	2,449,630	1,641,197	34,556,682

4. Breakout Cost

Breakout cost refers to the costs of identifying and establishing second sources for material. DoD policy in recent years has heavily emphasized competition in contracting, and goals have been established for the proportion of items that are procured competitively. The costs of this effort have increased as indicated in Table 5. The data show a sharp increase in labor costs from 1983 to 1985. This can partly be explained by the inclusion of breakout costs. From 1985, breakout costs are included as a special item in the compilation of the total annual ordering cost. All values are in nominal dollars:

TABLE 5

BREAKOUT COSTS

Year	Cost
1985	2,477,130
1986	2,626,752
1987	4,476,927
1983	5,839,713

The breakout cost is a genuine cost of doing business, and should be included when the ordering cost is computed. However, because breakout cost only pertain to some of the data points, the inclusion could potentially distort the analysis. Preliminary tests revealed that the exclusion of the breakout cost did not change any of the conclusions from the regressions. Breakout cost is therefore included as part of the ordering cost in the remaining part of this thesis, unless otherwise explicitly stated.

B. REGRESSION ANALYSIS

This study was initially designed to compare the workload over a number of years with the corresponding total administrative ordering cost. The hypothesis was that if a strong correlation was found between workload and cost, then the present method of identifying relevant costs would indeed be applicable. Conversely, if total ordering cost did not seem to vary according to changes in the workload, the present method for determining the ordering cost parameters would be inaccurate.

Under ideal conditions, a multiple regression analysis should be performed. Total ordering cost would be the dependent variable, and the various types of buys would be independent (explanatory) variables. The resulting coefficients of the independent variables would be a measure of the cost of each purchase type. These coefficients would then be subjected to standard statistical tests to determine if the results were significant.

1. Consolidation of Purchase Categories

Unfortunately, few data points were available to perform a multiple regression analysis according to the method outlined above. Ways to consolidate the data set were therefore sought. One potential remedy was to reduce the number of purchase categories. The purchase orders and the delivery orders were therefore grouped into a "small purchases" category, and the advertised contracts and the negotiated contracts were grouped into a "large purchases" category.

As can be seen from Table 2, the difference in cost parameters for purchase orders and delivery orders is small, especially when compared to the difference between purchase orders and negotiated contracts. Likewise, the difference in cost between negotiated and advertised contracts is

relatively minor. Therefore, no significant loss of accuracy would be expected by reducing the number of categories as described.

2. Number of Data Points

The number of small and large purchases, and the relative magnitude of each is shown in Table 6.

TABLE 6

SMALL AND LARGE PURCHASES

Year	Small	Large	Small(%)	Large(%)	Sum
1976	92108	5904	93.98	6.02	100.00
1977	Data not available				
1978[5]	91168	6968			
1979	95360	7288			
1980	106055	8105			
1981	118248	7040	94.38	5.62	100.00
1982	106608	6824	93.98	6.02	100.00
1983	99950	4321	95.86	4.14	100.00
1984	Data not available				
1985	50502	3610	93.33	6.67	100.00
1986	46096	4418	91.25	8.75	100.00
1987	46143	4491	91.13	8.87	100.00
1988	49078	6117	88.92	11.08	100.00

The data in Table 6 show that the percentage of purchase actions in the small purchase category is fairly stable, with values ranging from 88.92 - 94.38. The average proportion was 92.9 percent for small purchases and 7.1 percent for large purchases.

As indicated in Table 3, only the total number of purchase action for the years 1978 - 1980 is available. But because the distribution is fairly stable, the proportion of small and large purchases can be estimated by averaging. This is done so as not to lose any data points in the analysis.

3. Deflator Index

All values in Table 4 are given in current year (nominal) dollars. In order to make these comparable from year to year, some deflator needs to be used to compensate for the effect of inflation and wage increases over time.

[5]Distribution for the years 1978 through 1980 is estimated based on average values for the remaining years.

Labor costs were therefore deflated by the annual increase in the pay scale for civilian personnel.

Since labor cost represents the vast majority of total cost, the same deflator for the other cost categories was used. This was presumed to be sufficient to take the effect of inflation into account for these other cost categories.

The inflation indices shown in Table 7 were constructed with a base year of 1976 = 100. The indices are based on data for expected pay raises from the annual compilation of total variable costs at SPCC. As verified by actual data obtained through the Comptroller's office of the Naval Postgraduate School, the expected and actual pay raises turned out to be practically identical.

TABLE 7

DEFLATOR INDEX

Fiscal year	Wage raise	Index value
1976		100.0
1977	7.0	107.0
1978	5.5	112.9
1979	7.0	120.8
1980	9.1	131.8
1981	4.8	138.1
1982	4.0	143.6
1983	0.0	143.6
1984	4.0	149.4
1985	3.5	154.6
1986	0.0	154.6
1987	3.0	159.2
1988	2.0	162.4

4. Making Data Comparable

A requirement for performing the analysis was that the data would be comparable from year to year. It appears that the costs of leave, personnel benefits, and training have been inconsistently treated over the years. Leave and personnel benefits are calculated as 21 percent and 8 percent respectively of direct labor cost, and should be included in the ordering costs. For the years 1983 - 1986 (inclusive) these indirect personnel costs were added to the labor costs.

However, in preparation of the data for 1987 it was discovered that both of these costs were already included in the labor cost data, and had been so for many years. Consequently, the procedure was changed so as not to count these elements twice. It was also determined that four percent of direct labor ought to be added to cover the cost of training. This has been done since 1987.

In the years 1976 - 1982 personnel benefits, but not leave were added. Since personnel benefits already had been included in the data, this was a mistake. To reflect the true nature of the development of the labor costs over time, data presented in Table 4 were adjusted for these duplications, and subsequently deflated by the index developed in Table 7. The results of these transformations are presented in Table 8.

TABLE 8

ADJUSTED COSTS - 1976 DOLLARS

Year	Labor	ADP	Misc.	Adj. total
1976	9,963,960	545,616	636,944	11,146,520
1977	Data not available			
1978	10,377,622	616,982	940,050	11,934,655
1979	10,189,200	614,828	800,196	11,604,223
1980	9,388,568	589,856	541,360	10,519,783
1981	10,114,730	876,525	567,205	11,558,460
1982	10,907,790	257,220	528,061	11,693,071
1983	13,416,397	698,579	625,293	14,740,269
1984	Data not available			
1985	17,868,340	770,697	882,092	19,521,129
1986	19,025,478	649,524	600,093	20,275,095
1987	15,906,118	829,356	1,099,357	17,834,831
1988	18,756,979	1,508,169	1,010,439	21,275,587

The data in the last column of Table 8 are used as the dependent variable in the regressions, unless otherwise stated. A marked increase in total ordering costs after 1983 should be noticed. This coincides with a marked decrease in the total number of line items, ref. Table 3. Figure 2 shows how total variable cost divided by the number of line items has varied over time.

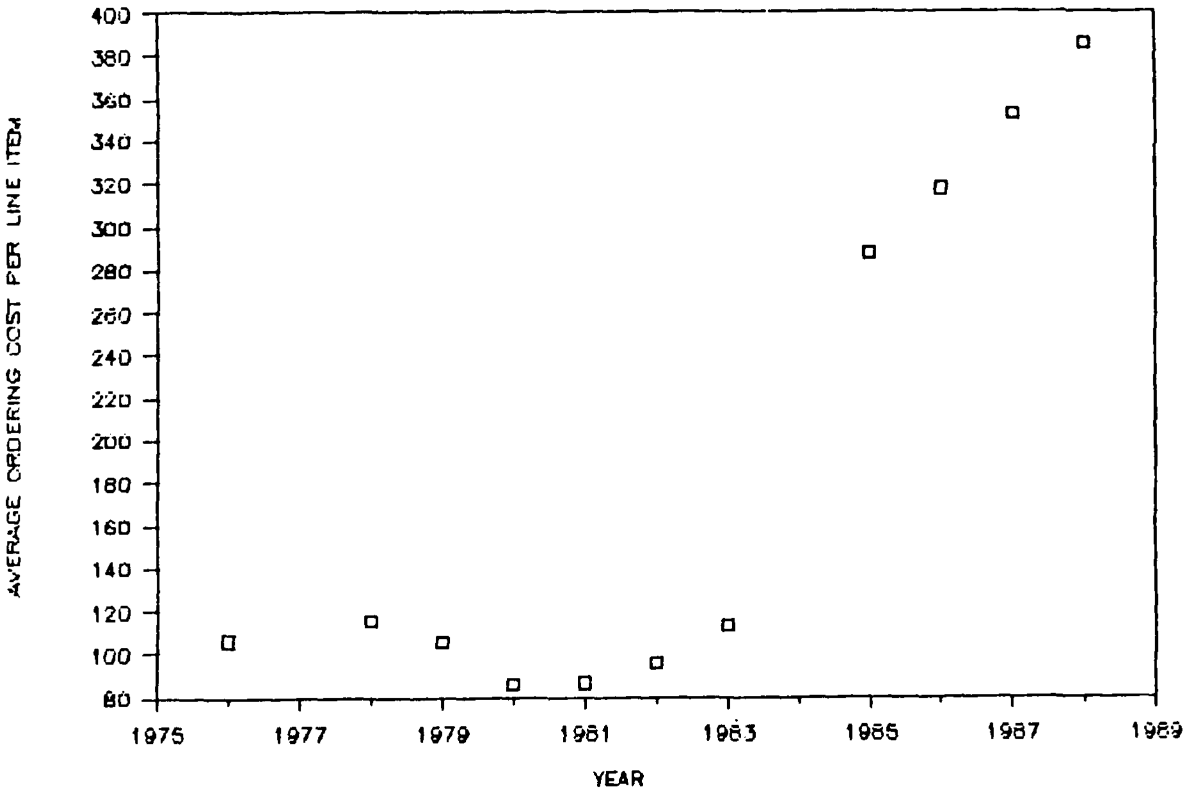

Figure 2: Average Ordering Cost per Line Item

Expressed in percentage terms, the data in Table 8 show that labor costs were the dominating cost element, and accounted for 86-93 percent of total ordering cost. The proportions of TOC, as represented by labor cost, ADP cost, and miscellaneous costs are shown in Table 9.

TABLE 9

LABOR, ADP AND MISCELLANEOUS COSTS IN PERCENT OF TOTAL ORDERING COST

Year	Labor	ADP	Misc.	Sum
1976	88.63	5.25	6.13	100
1977	Data not available			
1978	86.24	5.45	8.31	100
1979	86.96	5.67	7.37	100
1980	88.49	6.00	5.51	100
1981	86.65	8.11	5.25	100
1982	92.79	2.36	4.85	100
1983	88.73	5.95	5.32	100
1984	Data not available			
1985	89.36	4.96	5.68	100
1986	92.20	4.05	3.74	100
1987	89.19	4.65	6.16	100
1988	88.16	7.09	4.75	100

ADP cost for 1982 seems somewhat out of line with those of the other years. However, it was not possible to determine what had caused this particular behavior. Apart from that, the pattern of the data seems quite stable.

5. Alternate Measures of Workload

As was discussed in Chapter III, there is a considerable backlog in terms of contract actions at SPCC. Since the bottleneck seemed to be in the contracting department, the workload in this department was examined. Table 10 shows the number, dollar value of contract actions (including modifications), and the average paid employment (APE) figure for the years 1977 -1987. The dollar values are given in millions of dollars. The costs of commercial repair actions are not included.

TABLE 10

CONTRACT ACTIONS AT SPCC

Year	Contracts	Value	APE
1977	78203	531676	311
1978	103111	444232	298
1979	107299	531337	290
1980	92577	698404	289
1981	111621	1054800	309
1982	106559	1271868	323
1983	94328	1489797	351
1984	71270	1337716	389
1985	79916	1404789	423
1986	68598	1279790	407
1987	58150	1439914	428
1988	*	*	408

NOTE:
* Data not available

The data for contracting actions contain provisioning as well as resupply. Consequently, the numbers cannot be compared directly with the number of line items presented in other statistics. Further, the number of line items per contract action may change from year to year. Despite this, the workload as measured by line items or contract actions follows the same general pattern, as displayed in Figure 3.

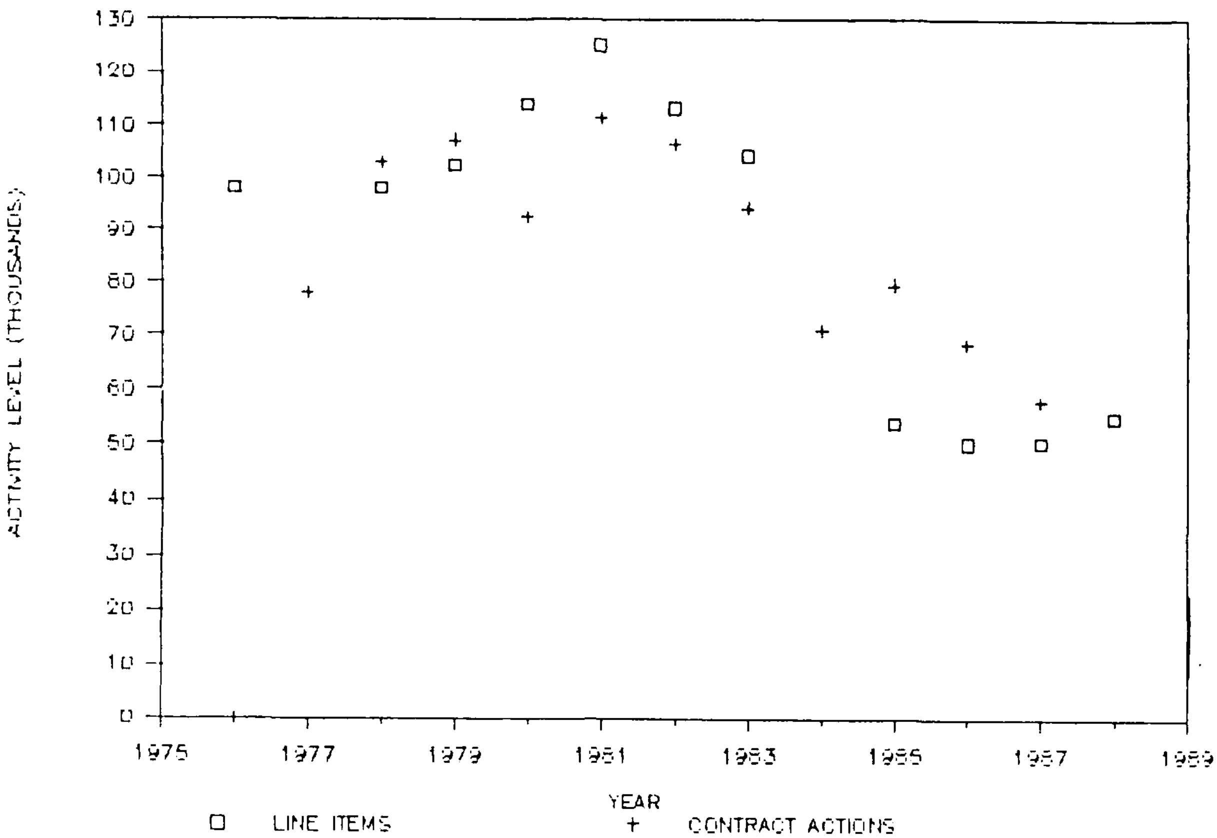

Figure 3: Two Ways of Measuring Workload at SPCC

The number of line items was chosen as the explanatory variable, because the ordering cost is supposed to reflect the cost to order an item, rather than the cost to let a contract. However, because the data in Figure 3 tended to vary in the same manner, similar conclusions from the analyses would have been reached, had contract actions been used as the explanatory variable instead.

The average workload per employee in the contracting department was computed on the theory that workload per employee could somehow explain the variations in total workload and/or in total ordering cost. No such causative relationship was found, as the regressions resulted in a low R^2 values. Figure 4 depicts average number of line items purchased per employee in the contracting department.

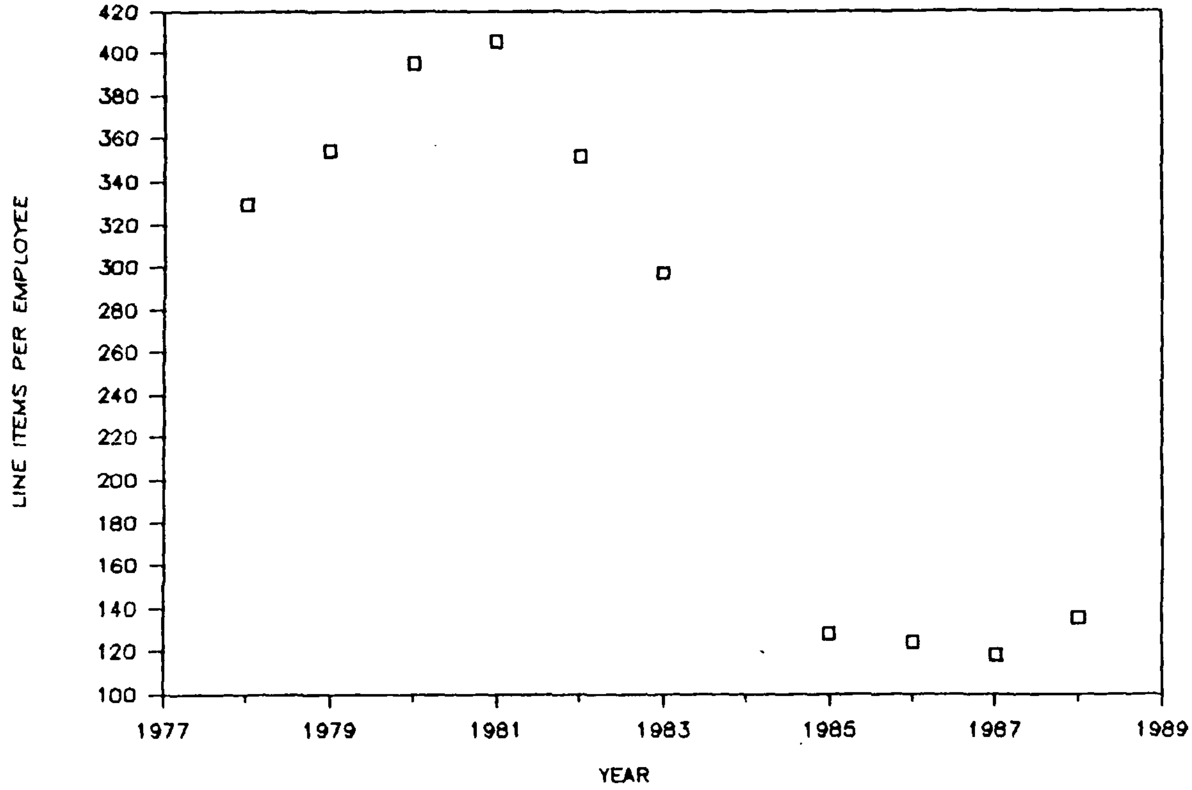

Figure 4: Average Number of Line Items per Employee

6. Contract Modifications

In SPCC's calculations of cost to order parameters, the work associated with contract modification is included. In the summary of source data used at SPCC [Ref. 27], it is stated that in the computation of total ordering cost:

> Hours expended on cancellations and reconsignments were included in the total; however, line items processed by these methods were excluded since no line items were actually procured by reconsigning or cancelling.

One might argue that the cost of modifications should be excluded from the estimate of the ordering cost. However, in this thesis modifications are viewed as an ordinary part of the business. The ordering cost should by definition include all costs incurred as a function of placing an order. Consequently, if a number of modifications would be required, before a contract eventually is let, then this should be seen

as an integral part of the ordering process, and the costs should be included.

7. Summary

The primary focus of the regression analysis is to estimate the true ordering costs incurred at SPCC. This section has presented the data on which the analysis is based. The data analysis and interpretation of findings are presented in Chapter V.

C. THE SIMULATION MODEL

1. Holding Costs

As was pointed out in Chapter III, capital cost and storage cost are determined by DoD, whereas the rates for obsolescence and other losses should be determined based on the actual disposal rates. Originally this study was intended to verify the current rates based on actual calculations. However, it soon became apparent that data were not available to support such an approach. Instead, changes in TOC resulting from different assumptions for the combined obsolescence and other loss rates were analyzed by means of Monte Carlo simulation.

The procedure involved defining a representative sample of items. The present parameters for ordering and holding costs were used to calculate unconstrained EOQs and the corresponding number of buys that would result for each item in the sample per year. The simulations were done by keeping all the parameters fixed, except for the holding cost rate, which was allowed to vary according to different possible probability distributions.

2. The Simulation Model

A spreadsheet EOQ model was built in LOTUS 1-2-3, and a simulation application by the ENFIN Software Corporation was used to perform the simulation. The objective of the simulation was to find the X-cost. This cost has been defined as the extra cost incurred by having imperfect

knowledge of the parameters in the EOQ model. The X-cost is the result of ordering quantities which differ from the optimal EOQ. Two instances where this may happen are discussed in this chapter. The first is when a single holding cost rate is applied for a number of items with different holding cost rates. The other is when ordering quantities for some reason are constrained.

The spreadsheet model was designed to compute the X-cost resulting from constraining the number of buys per year. The model and the cell formulae are presented in Appendix C along with a sample of the simulation output. The assumptions and logic of the model are explained in the remainder of this chapter.

3. **The Sample**

The sample of items to be used in the simulation was constructed based on output from a program used at SPCC called "CARES". The inventory of active items in the 1H cognizance group (consumables) as of March 1987 is divided into 36 four digit cognizance group (cog) categories. The list is presented in Table 11.

TABLE 11
1H COG BASE MARCH 1987

Cog (1)	Items (2)	Demand (3)	Value (4)	Price (5)	Avg. = (6)	VAD/Item (7)
1HN1	1185	43757	14893950	340.38	36.93	12568.73
1HN2	2178	14141	7405833	523.71	6.49	3400.29
1HN3	15575	9516	10363646	1089.08	0.61	665.40
1HS1	202	5985	1349320	225.45	29.63	6679.80
1HS2	737	4695	2141121	456.04	6.37	2905.18
1HS3	5473	4222	1299040	307.68	0.77	237.35
1HOA	1356	73465	29234562	397.94	54.18	21559.41
1HOB	1798	12177	12283474	1008.74	6.77	6831.74
1HOC	16006	16787	17739338	1056.73	1.05	1108.29
1HOD	28	2060	1599736	776.57	73.57	57133.42
1HOE	66	437	611309	1398.88	6.62	9262.25
1HOF	1245	363	2066313	5692.32	0.29	1659.68
1H1A	650	26289	21605058	821.83	40.44	33238.55
1H1B	1625	10550	16491424	1563.17	6.49	10148.56
1H1C	16239	9251	17350405	1875.52	0.57	1068.44
1H1D	56	2009	2160891	1075.61	35.88	38587.33
1H1E	150	1053	806771	766.16	7.02	5378.47
1H1F	1336	804	4910478	6107.56	0.60	3675.50
1H2A	538	19210	16985618	884.21	35.71	31571.78
1H2B	853	5813	6926078	1191.48	6.81	8119.66
1H2C	5236	4858	8946715	1841.65	0.93	1708.69
1H2D	12	526	631157	1199.92	43.83	52596.41
1H2E	23	136	282238	2075.28	5.91	12271.21

TABLE 11 (Continued)

1H2F	122	131	1564276	11941.04	1.07	12821.93
1H3A	1311	42199	31695046	751.09	32.19	24176.23
1H3B	2323	15856	20346798	1283.22	6.83	8758.84
1H3C	5269	12828	18670379	1455.44	0.84	1222.76
1H3D	162	4316	9978530	2311.99	26.64	61595.86
1H3E	348	2342	3758965	1605.02	6.73	10801.62
1H3F	2252	2143	5176423	2415.50	0.95	2298.58
1H4A	1898	85350	56130213	657.65	44.97	29573.34
1H4B	2068	14465	24403229	1687.05	6.99	11800.40
1H4C	8631	7391	15181635	2054.07	0.86	1758.96
1H4D	257	8072	7813527	967.98	31.41	30402.82
1H4E	200	1405	1432892	1019.85	7.03	7164.46
1H4F	923	845	3844511	4549.72	0.92	4165.23

NOTE:
The columns in table 12 depict the following:
(1) Four digit cog.
(2) Number of line items in the four digit cog.
(3) Forecasted demand of line items.
(4) Value of demand (number of line items times price).
(5) Average price. Column 4 divided by column 2
(6) Average number of line items per requisition. Column 2 divided by column 1
(7) Average value per requisition, column 6 multiplied by column 5.

Pareto's Law of maldistribution was briefly discussed in Chapter II. By sorting the data according to decreasing values of annual demand, it was found that cogs representing 8.9 percent of the line items accounted for 46.1 percent of the total value of annual demand. However, because only average values are available for each cog, the actual maldistribution is dampened. This happens because all the extreme values are lost when the line items are grouped by cog. A similar ranking by line item would undoubtedly result in an even clearer demonstration of Pareto's law.

Several attempts were made to manipulate the data in Table 11 so as to separate the high and the low value items. The intention was to use the resulting data as parameters for the simulations. Since the distribution within each cog is unknown, a hypothetical data set was created instead. This was based in part on the data in Table 11. Thus, all data for the simulation are fictitious, but are not outside the realm of realism.

4. Input Parameters

An item universe consisting of 100,000 line items was constructed, and the value of annual demand for these was set to $400 million. One half of the line items i.e., 50,000 were assumed to have an average demand of .25 per year. The average price of each of these items was set at $800, thus representing an annual demand of $10 million. Because of the slow turnover and low average unit price, these items were assumed to fall in the small purchases category.

Another 45,000 articles were represented in the small purchases category. They were valued at $250 each, and an annual demand of eight was assumed. The remaining 5,000 articles would represent approximately 90 percent of the value of annual demand. For these articles a price of $5,000, and an annual demand of 12 were assumed. These were considered to fall in the large purchases category. Ordering costs of $700 and $1700 for the small and large purchases respectively, were used in the simulation.

5. Constraints

The constraints were defined in terms of maximum and minimum number of buys per year. Thus, a maximum constraint of four is equivalent to buying a minimum of three months' supply each time. Similarly, a minimum constraint of one third implies that a maximum of three years' supply can be bought at one time. The effects on TVC of various constraints were found by recalculating the spreadsheet. The findings are presented in the next chapter. The constraints were set so as to be inactive during the simulations. This was done to isolate the effect of varying the holding cost rate. The model can handle any reasonable combination of input parameters, and strictly positive constraints.

6. The Simulation Parameter

Since the actual distribution of the holding cost rate is unknown, several possibilities were explored. The

simulations were performed using two different types of distributions, the triangular and the uniform. The triangular distribution requires that an upper and lower bound, plus the mode be specified. Because the holding cost rate would include capital costs and storage costs even if the obsolescence rate was zero, the lower bound was set at 5 percent. The upper bound was set at 55 percent. Although there may be examples of spare parts becoming obsolete by the time they arrive at the stock point, a minimum expected useful life of two years was assumed. The modal (most common) rate was set at 10, 23, and 36 percent respectively for three different simulation runs. Each setting was simulated 2000 times, and the resulting distribution was recorded.

The triangular rather than the normal distribution was chosen because the latter requires that the standard deviation be specified. In this case the standard deviation is unknown.

Three different scenarios were simulated for the uniform distribution. This distribution assumes that an upper and lower bound is specified. All values within this interval are equally likely to occur. The implication is that there is even less certainty about the true probability distribution than if the triangular distribution is used. The lower and upper bounds for the three scenarios were 5-41 percent, 5-55 percent, and 11-35 percent respectively. The first one uses the current value of 23 percent as a midpoint. The second ranges over the total likely span. The third one is similar to the first, but has a tighter distribution.

7. The Simulation Objective

The simulation objective is to find the extra cost (X) incurred due to the lack of knowledge of the (true) holding cost rate. If a holding cost rate (I) of 23 percent is used in the model, a given EOQ will result from the

calculations. However, if the true holding cost (I^T) is different from 23 percent, the calculated EOQ will be different from the optimal, denoted Q^T. The actual holding costs are one half of EOQ times I^T.

If I is greater than I^T, the resulting EOQ will be smaller than Q^T. Because the holding costs rate is overestimated, too little inventory is kept relative to the optimal situation. This lower than optimal inventory level gives lower holding costs than would have been the case if Q^T had been bought. But this saving is more than offset by the higher ordering costs that are incurred by buying too small quantities too frequently.

The opposite situation occurs when the real holding cost rate is higher than expected. In that case too much inventory is kept, resulting in higher than necessary holding costs. The savings resulting from less frequent buys will not be large enough to offset the increase in holding cost. The increase in TVC resulting from uncertainty in the parameter estimates was depicted in Figure 1.

8. Differentiated Holding Cost Rates

As was described in Chapter III, SPCC uses a 23 percent holding cost rate for all consumable items. This rate assumes a universal risk of obsolescence and other losses of 12 percent. Two questions then arise. One, is there truly no variation among the different items, and two, is 12 percent a reasonable average value? The presumption that the rate is independent of the type of item in question is quite unrealistic. The problem is that no firm data are available to indicate what the true rates are like.

One of the conclusions of Chapter III was that using average parameter values for several items, will not give the overall lowest costs. Instead, each deviation from the individual optimal parameter will be accumulated.

The simulations made it possible to analyze the effect on TVC of applying a single holding cost rate of 23 percent for all items, when in fact the distribution of the (true) holding cost rate is as described by the probability distribution. The results are presented in Chapter V.

V. DATA ANALYSIS AND INTERPRETATION OF FINDINGS

One of the objectives of this study was to determine the relationship between workload and total variable ordering cost (TOC). The presumption was that changes in TOC, as measured in constant dollars, could be attributed to changes in total workload. Consequently, a way of determining the ordering cost parameter for the EOQ model, would be to compare TOC and workload over a number of years. This method, however, failed to determine a positive correlation between workload and the alleged total ordering costs. The analysis that led to this conclusion is presented, and its significance is interpreted in this chapter. Furthermore, this chapter presents the results of the simulation, based on various assumptions for the holding cost rate.

A. DATA ANALYSIS

1. Regression Analysis - Measures of Goodness

The analysis of ordering cost was performed using standard regression techniques. Results were evaluated in terms of the slope of the independent variable(s), the coefficient of determination (R^2), and the standard error of the estimates. The dependent variable was total ordering cost, and the independent variables were various measures of workload. Results of the regression runs were interpreted as follows:

The Y intercept would be a measure of fixed cost. Since the source data presumably only included variable cost, the intercept should ideally be zero. Any positive intercept would indicate that part of the costs were, in fact, fixed over the relevant interval of activity.

The slope of the independent variable(s) should be positive to indicate that activity and costs varied in the same direction. The slope should also be significantly

different from zero. The measure of significance is the common T-test. This test measures the relative size of the standard deviation. Finally, the regression equation should have a high value of R^2 to be acceptable. "High", in this context, is at least 80 percent. These criteria would have to be met simultaneously to provide valid results. As it turned out, none of the regression relationships satisfied all of the criteria. The next paragraphs present some of the alternative independent variables that were explored. At least one reason why they failed to meet the criteria is discussed.

2. Regression Runs

All of the regression runs that are described in this chapter are linear regressions, as the assumption is that total ordering cost is a linear function of the number of orders per year.

Regression number one used total number of line items as the independent variable, and forced the intercept to zero. This resulted in an R^2 of 3 percent. Whenever the alternative of forcing the intercept to zero was investigated, very low R^2 values were produced. This option is therefore omitted from the following discussion, although it was explored for all possible independent variables.

Regression number two used the same independent variable, but without a forced intercept. This gave an R^2 of 78 percent, but a negative slope for the regression.

Regression number three was a multiple linear regression using the small and large categories as explanatory variables. R^2 then increased to 79 percent. The slope of the small purchase variable was still negative, whereas the slope of the variable for large purchases was positive. The Y-intercept was at \$22.4 million. This figure is higher than any of the total cost values in the source data. This can be attributed to the negative slope for the

small purchases variable. The negative slope is interesting, and is addressed later in this chapter.

The marked drop in number of purchase actions between 1983 and 1985 has been pointed out. To capture the effect of this drop, a dummy variable was introduced. This was done by assigning a zero to all the years up to 1983, and a one to the years from 1985 on. Total ordering cost was then regressed against the total number of purchase actions and the dummy variable. This produced a high R^2, 90.3 percent. The variable for the total number of purchase actions still showed a negative slope, and was also not significant in terms of the t-test at the 90 percent confidence level.

Another attempt to use two explanatory variables, was to take the total number of purchase actions as one independent variable, and the ratio of small to large purchases as the other. Again a fairly high R^2 was obtained, 88.7 percent, but still with a negative coefficient for the workload variable.

Other runs included evaluations of small and large purchases individually, and the ratio of these with and without the dummy variable. None of these combinations satisfied the criteria for establishing any positive relationship between workload and total variable costs.

The overall highest R^2 value was obtained by using three explanatory variables, the dummy variable previously introduced, the number of small purchase actions, and the number of large purchase actions. This gave a value of R^2 of 91.7 percent. However, the t-test showed that the slopes of the latter two explanatory variables were not significant at the 90 percent confidence level. Further, since the dummy variable was the dominating factor, the result is almost useless in terms of a practical application.

3. Breakout Cost

The possibility that the breakout cost could have a substantial impact on the result of the analysis was considered. The regressions were therefore replicated on total ordering cost after excluding the breakout cost. All conclusions remained unchanged.

4. Time Perspective

The efforts to make sure that the data were comparable over the whole time span of the study were discussed in Chapter IV. Nonetheless, the possibility exists that changes have taken place without being reflected in the data. In an attempt to explore this possibility, data from the last four years were analyzed separately, using the same procedures as explained for the entire data set. In no instances were R^2 values higher than 30 percent found. Thus, a shorter time perspective did not produce more valid results.

B. INTERPRETATION OF FINDINGS

Except when forced, the y-intercept was consistently found to be significantly different from zero at any reasonable confidence level. Furthermore, whenever high R^2 values were found, the results also indicated an inverse relationship between ordering cost and activity. Graphically this is depicted in Figure 5 which plots total ordering cost, exclusive of breakout cost, against the number of line items purchased.

Figure 5 exhibits a trend which is contradictory to what would normally be expected. As it turns out, annual total ordering cost (TOC) is relatively low for the years with the highest activity in terms of total number of line items purchased. The finding indicates that the present procedures at SPCC do not correctly identify variable costs, despite compliance with DoD Instruction 4140.39.

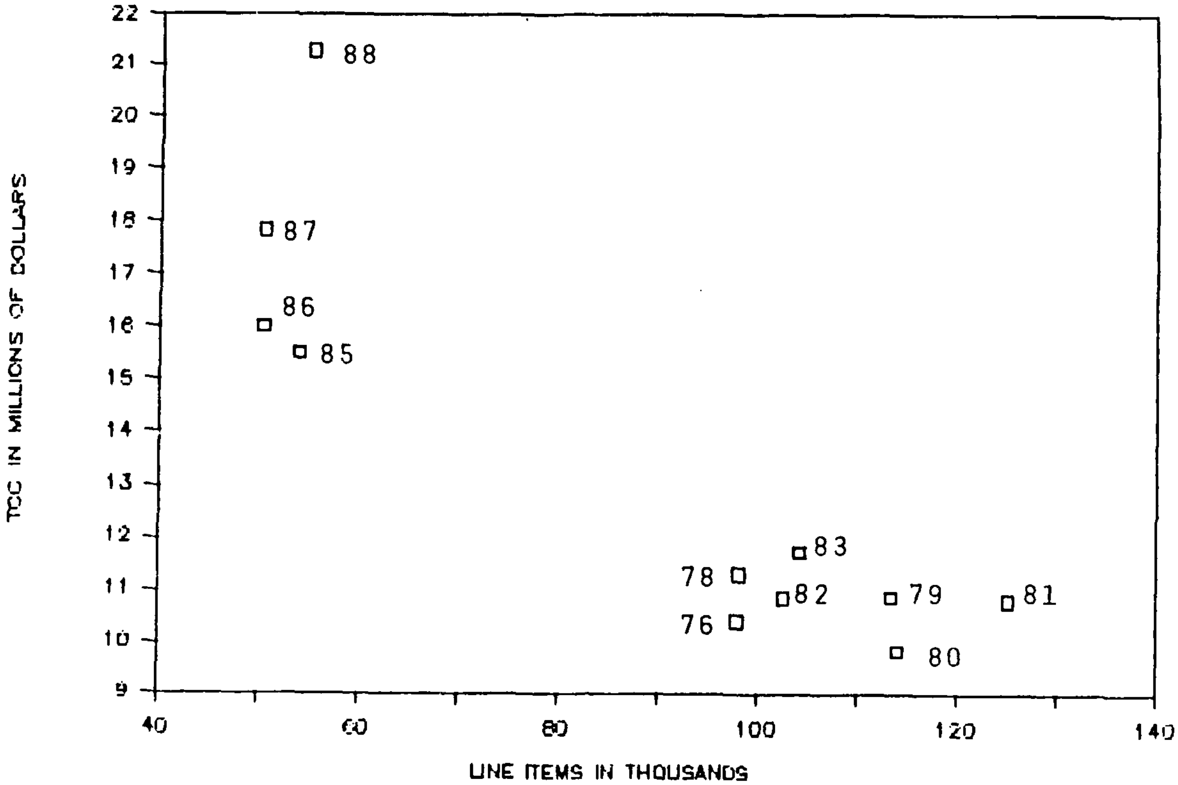

Figure 5 Total Ordering Cost Versus Line Items

There is no evidence to suggest that total ordering cost, as now measured, varies as a result of different activity levels. On the other hand, a regression of TOC in current dollars against years resulted in R^2 of 90.8 percent, Y-intercept of 1973.12, and a positive slope of 0.00000044. The T-values indicated better than 99.999 percent confidence that total ordering cost has increased over time. This result suggests that it would be better to use a time related variable than to use an activity related variable to explain changes in total ordering cost. Further research would be needed to identify one or more such time related variables.

An interesting observation is that total "variable" ordering cost increased from 1983 to 1985. This happened despite the additional constraints imposed on the EOQ

ordered. Presumably, the justification for constraining the EOQ model was to reduce the ordering cost, or to reduce the backlog of purchase actions. The data do not indicate that these goals were achieved. A reasonable conclusion is, therefore, that some external factor caused the total ordering cost to increase.

The ordering cost data show that especially the labor cost has risen in later years, partly because of increased breakout costs. Another explanation is the increase in the number of personnel in the contracting department. Average paid employment (APE) is plotted against time in Figure 6.

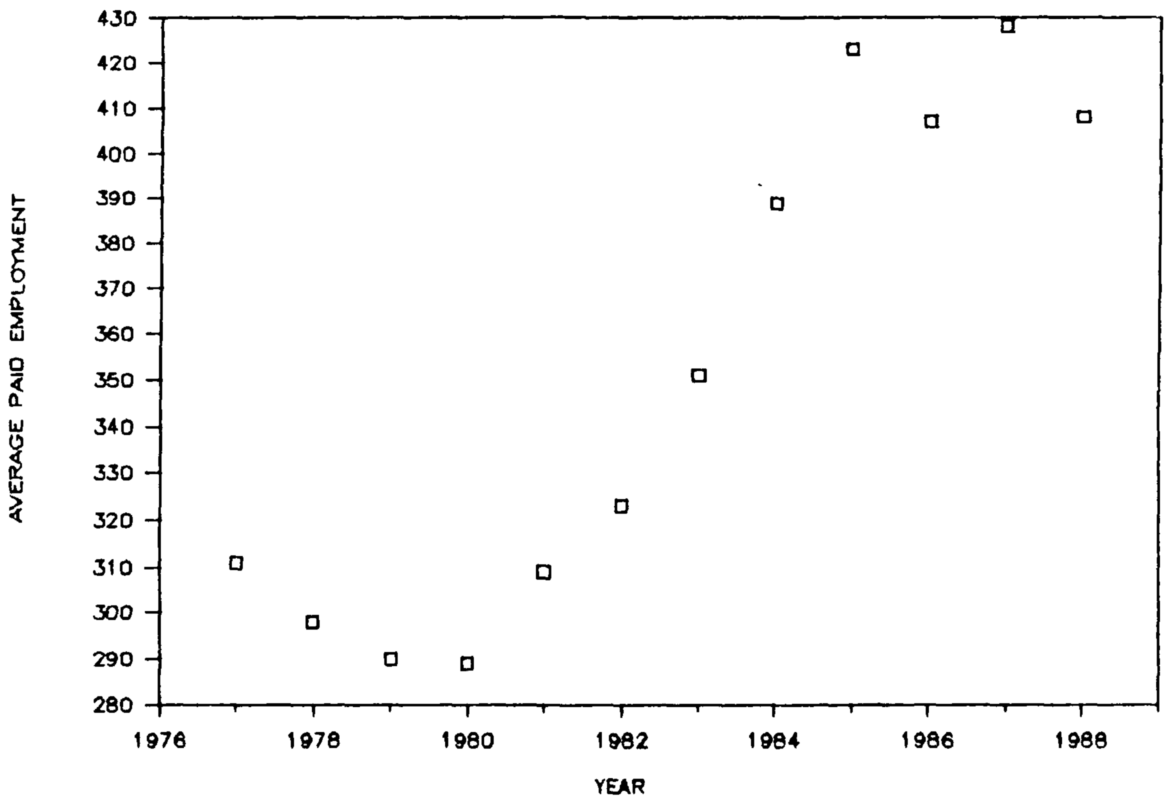

Figure 6: Contract Personnel over Time

A regression of APE versus TOC (adjusted for inflation) gives R^2 of 89.3 percent. Thus, it can be concluded that there is a strong correlation between personnel strength in the contracting department and total variable cost. At the

same time, the average number of line items per employee has decreased markedly, as was illustrated in Figure 4. Together, these factors totally dominate any impact on TOC resulting from changes in the number of orders.

1. Productivity Curve

A way of presenting productivity development is portrayed in Figure 7. This figure shows TOC divided by total number of line items plotted against number of line items purchased. The theoretical shape of such a productivity curve has the form of a U, with the minimum indicating 100 percent capacity utilization. Both under- and overutilization will tend to increase the unit cost of the activity.

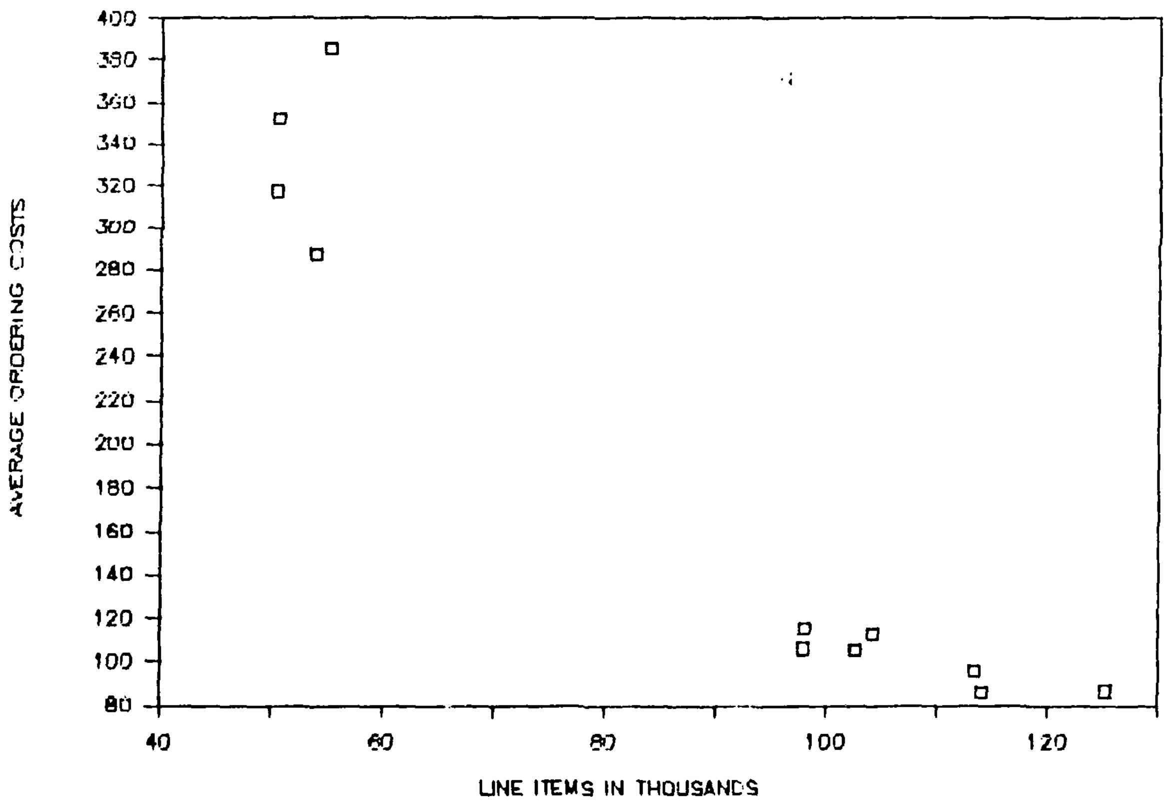

Figure 7: Productivity Curve

The data points in Figure 7 are identified by year. It is quite apparent from the plot that the ordering costs increased sharply from 1983 to 1985. Conversely, the productivity decreased sharply in the same period. This could have indicated underutilization of capacity. However, there has been a considerable backlog of work in recent years, suggesting that some other explanation is more likely.

2. Implication of Findings

The finding that total ordering cost is independent of the total number of buys, has several interesting implications. It appears that the present method of identifying total ordering cost is inadequate, as it does not seem to capture the marginal costs involved in the process. If further research should indicate that this problem exists beyond SPCC, the procedure described in DoD Instruction 4140.39 should be changed accordingly.

If the ordering cost parameters, as now computed, are incorrect, neither the calculations of the EOQs, nor the resulting number of annual buys, will be optimal.

3. Limiting the Number of Purchase Requests

The presence of a backlog of purchase requests at SPCC, despite attempts to reduce the number generated, might indicate that the capacity of the ordering department is constrained. If the capacity cannot be easily adapted to the workload in any given year, the use of EOQ calculations for all items may be suboptimal. An alternative approach might be to calculate the total capacity in terms of number of purchase actions. This capacity should then be allocated between unconstrained and constrained EOQs, so as to minimize total variable cost. This would involve ranking items in terms of their contribution to TVC.

Ordering an item less frequently is equivalent to increasing the average inventory level. Ideally then, this practice should be restricted to items with a relatively low

holding cost rate. If the holding cost is relatively modest, a periodic review system might be more appropriate than a continuous system. A periodic review system means that orders are placed at regular intervals. No stock visibility is kept between orders. A periodic review system has two major advantages. The cost of record keeping is greatly reduced, and the ordering frequency can be tailored to suit the capacity in the purchasing department. Further research would be needed to evaluate whether introducing a periodic review system for items with a low holding cost rate is a viable alternative at SPCC.

4. **Fixing the Number of Buys**

If increased buy quantities, or equivalently, reduced numbers of buys is a policy objective, it can be attained in the EOQ model by deliberately overstating the ordering cost, or understating the holding costs. However, the economic consequences of such a move should be thoroughly investigated beforehand.

A graphical representation of the effect of applying different holding cost rates can be seen in Figure 8. The X-axis depicts various holding costs as expressed in proportion to the present 23 percent rate. The Y-axis shows the relative impact in terms of number of orders. Thus, the point (1,1) on the plot indicates a number of purchase actions that would result with I=.23 and a given set of parameters for A, D and C. A 50 percent reduction in the applied holding cost rate would reduce the number of purchase actions by approximately 30 percent, provided the remaining parameters were kept constant.

Figure 8 demonstrates how changing the holding cost rate can be used as a means of regulating the number of purchase actions to a desired magnitude. The same effect can be demonstrated by keeping the holding cost rate fixed and varying the ordering cost.

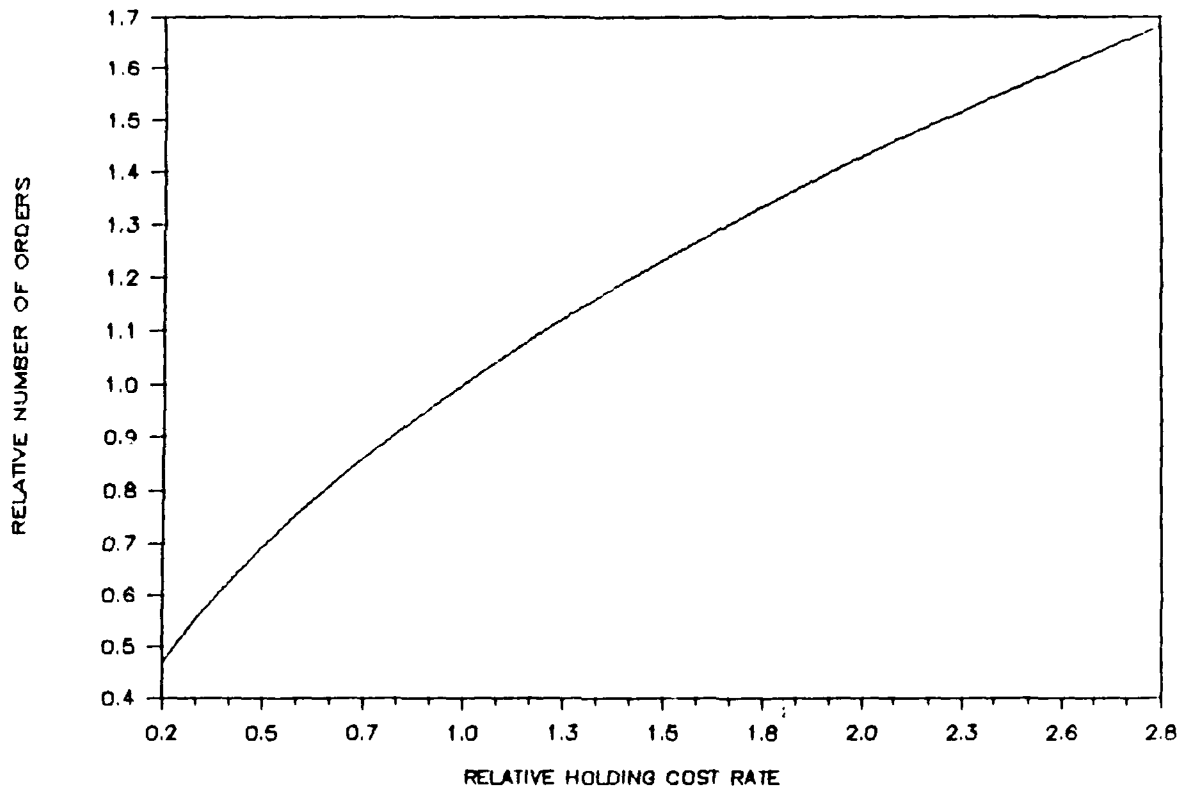

Figure 8: Relative Number of Buys versus Holding Costs

As explained in Chapter II, the practice of modest increases in the buy quantity over and above EOQ will not increase total variable costs very much. However, the risk of losses due to obsolescence increases with increasing inventory levels. It would therefore be desirable to apply the practice of overriding the recommended EOQ only in those cases where the risk of obsolescence is relatively small.

Unfortunately, the present UICP system is not structured to facilitate this type of judgment. The same rate of obsolescence is currently assumed for all consumable items. To get an idea of how costly such an assumption is, simulations were performed for various holding cost rates.

C. SIMULATION RESULTS

The simulation objective was to calculate the X-cost. Results are presented in Table 12.

TABLE 12

SIMULATION RESULTS

Mean	Standard dev.	Maximum	Distribution
3,542,421	3,162,747	9,867,915	UNIFORM .05-.55
339,458	327,128	993,714	UNIFORM .15-.31
842,298	840,812	2,523,922	UNIFORM .11-.35
2,040,773	2,411,706	6,864,185	TRIANGULAR .05,.23,.55
2,298,608	2,373,212	7,045,032	TRIANGULAR .05,.11,.55
2,729,585	2,654,351	8,038,287	TRIANGULAR .05,.35,.55
396,852	597,907	1,591,046	TRIANGULAR .11,.23,.30

The results should be compared to $83,049,989, which is the calculated total variable cost, based on a holding cost rate of 23 percent. The simulation results pertain only to the hypothetical sample as described in the previous chapter. However, some general conclusions can be drawn. The results show that the standard deviation is of about the same magnitude as the mean, indicating a wide distribution. The way results are computed in the simulation model, the X-cost is zero when I=.23. In all other cases, the X-cost is some positive value. This means that the lower bound for the distribution of the X-cost is zero, and that a finite upper bound exists. The "maximum" column is computed by adding two standard deviations to the mean. Thus, according to Chebychev's theorem, at least 75 percent of all observations will lie between zero and this value. The result from the last of the simulations presented in Table 12, indicates that the X-cost is less than the mean plus two standard deviations more than 95 percent of the times.

Table 13 clearly shows that only a few observations are very far above the mean. However, these few observations weigh heavily in the computation of the X-cost. This implies that the bulk of the potential savings could be realized if the few items with extreme holding cost rates could be

identified. The factor that would cause such extreme rates would most likely be the obsolescence rate.

TABLE 13

DISTRIBUTION OF X-COSTS

Range	Frequency	Distrib. %	Accl. %	Accl. #
0 - 385.3	1387	69.35	69.35	1397
385.3 - 770.7	315	15.75	85.10	1702
770.7 - 1,156.0	109	5.45	90.55	1811
1,156.0 - 1,541.4	59	2.95	93.50	1870
1,541.4 - 1,926,7	42	2.10	95.60	1912
1,926.7 - 2,312.1	36	1.80	97.40	1948
2,312.1 - 2,697.4	31	1.55	98.95	1979
2,697.4 - 3,082.8	10	.50	99.45	1989
3,082.8 - 3,468.1	6	.30	99.75	1995
3,468.1 - 3,853.4	5	.25	100.00	2000

Mean: 396.8   Standard deviation: 597.9   Mode: 1.396

NOTE:
Range values are rounded, and expressed in thousands of dollars. 2000 simulations were run.

The simulation results reflect a situation where the true holding cost rate could be identified for each and every item. Clearly, that is an unrealistic assumption. However, to identify items with an expected obsolescence rate considerably higher or lower than the average might not be very hard to do, and would potentially yield considerable savings.

The costs of identifying these items would have to be traded off against the potential benefits. The simulation model can be useful in such a process.

1. The Cost of Constraints

The simulations were run without active constraints, and the results are not valid if such are imposed. The reason is that constraints on EOQs, or number of buys, interact with the parameters of the EOQ model. This means that the EOQ calculations can be manipulated to satisfy either an upper or a lower constraint by changing the parameters for I or A.

The LOTUS model is programmed so as to accommodate both a maximum and a minimum constraint at the same time.

When constraints are imposed on the EOQ model, TVC will increase. This follows from Chapter II of this thesis, which discussed how TVC increased if quantities that differed from the EOQ were ordered. This increase in TVC is in this thesis denoted the X-cost. The X-cost, resulting from various combinations of maximum and minimum constraints on the annual number of buys, is presented in Table 14. The X-cost is expressed in thousands of dollars. A holding cost rate of 23 percent for all items was assumed.

TABLE 14
CONSTRAINTS

Max	Min	X-cost
4	1/6	0
4	1/3	2,429
4	1/2	7,111
4	1	29,199
3	1/3	2,428
2	1/3	2,429
1	1/3	11,179

It can be noted that the X-cost increases rapidly as the constraints get tighter. Constraints of 4 and 1 are equivalent to buying a minimum of one fourth and a maximum of one year's worth of material each time. The way the parameters are set in the simulation model causes these constraints to be active for all items. In other words, under these circumstances the EOQ is never purchased, which explains the large size of the X-cost.

There may be good reasons for constraining the EOQ computations in practice. Typically, this would be the case where limited ordering or storage capacity exists. In such cases, the X-cost can be regarded as the shadow price of the capacity constraint. A simple spreadsheet model, such as the one included in Appendix C, can easily facilitate analyses of whether its better to increase capacity, or to constrain the EOQ under different scenarios.

The simulation application can handle multiple simulation variables. The analysis can therefore easily be

expanded by specifying a probability distribution instead of single estimates for the price and demand parameters.

VI. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of the research, major conclusions and recommendations for further research.

A. RESEARCH QUESTION NUMBER ONE

The first research question was to present a theoretical framework for the assessment of holding and ordering costs. This was done in Chapter II through a study of selected literature in the fields of inventory management, accounting, logistics, and operations research. Despite the large number of articles and books on the subject, there still seems to be uncertainty about how to treat various cost elements of the EOQ model.

The concept adopted from Lambert [Ref. 5], of dividing holding costs into four categories; capital costs, space costs, inventory service costs, and inventory risk costs, was found to be useful. The point that only marginal costs matter, was strongly made in this thesis, as was the point of including relevant opportunity costs.

The effect of inflation on the estimate of capital cost was not discussed in any of the literature reviewed. With the present rate of inflation of five to six percent, this element will considerably impact the estimate of holding cost. Currently, inflation is included in the 10 percent capital cost that is recommended in DoD Instruction 4140.39. It was concluded that inflation should <u>not</u> be included as part of the holding cost rate, and that a value closer to three percent be used for capital cost. This figure historically represents an average real rate of interest in the United States.

The DoD instruction specifies that storage cost be set to one per cent of the value of the item. This rate does not seem to incorporate the opportunity costs associated with

storage locations owned bv DoD. Where alternative uses of the facilities are realistic, opportunity costs exist, and should be included as part of the storage costs.

B. RESEARCH QUESTION NUMBER TWO

The second research question was to compare the theoretical framework, as discussed in Chapter II, to policies and practices at Ships Parts Control Center (SPCC). Inventory management at SPCC was discussed in Chapter III. It was pointed out that the inventory models actually used there, differ from Wilson's EOQ model in that they include military essentiality, and an implied shortage cost as additional parameters. Further, several constraints are imposed so that, in effect, quantities larger than the EOQ are frequently purchased.

Research question number two involved comparing total ordering cost, and the annual number of purchase actions at SPCC. These data were analyzed by means of regression analysis. The objective was to determine if annual ordering cost really was a linear function of the annual number of buys. Chapter IV described the data used for the analysis, and the methodology employed. Findings and implications were discussed in Chapter V.

The major conclusion was that total ordering cost did not vary as a function of the annual number of orders. Consequently, a crucial assumption for using the EOQ model is violated at SPCC. Two questions naturally then arise. Is there a better way of determining the ordering cost parameter, and if not, should a different inventory management technique e.g., a periodic review system be used for some or all of the items? Further research would be needed to answer these questions.

Since the number of buys was rejected as the explanatory variable for the behavior of total ordering cost, other possibilities were explored. It was found that the breakout

cost had risen considerably since 1984, which may partly explain why total ordering cost has increased in the same period. Another explanation is that the number of personnel in the contracting department has increased considerably in later years.

Despite the increase in personnel strength, the number of purchase actions has decreased substantially, particularly since 1983. On the other hand, the dollar value of contract actions has been fairly stable. Based on these data, a conclusion was reached that the overall productivity had decreased, presumably due to some change in the environment in which SPCC operates.

C. RESEARCH QUESTION NUMBER THREE

The last research question was to evaluate the economic implications of uncertainty in the parameter estimates for the holding cost rate. The original intent of this thesis was to compute actual obsolescence rates for some representative items and include these as elements in alternative measures of the holding cost rate.

DoD Instruction 4140.39 specifies that the rates for obsolescence and other losses are to be computed by dividing the value of items transferred to disposal by the average inventory value. However, data do not exist to do such computations. Even if such data had been available, the prescribed method would be an unreliable indicator of the true obsolescence rate. The reason is that changes in the inventory levels, over time are likely to distort the data to be used for the computation.

A simulation model with a hypothetical data set was constructed. In practice a rate of 12 percent has been used for all consumable items, to compensate for the risk that inventory should become worthless due to obsolescence and other factors. In the simulations, several distributions of holding cost rates were applied. The results indicate that

if the obsolescence rates vary over a large spectrum, the practice of applying an average rate can be quite costly. A model, as presented in Appendix C, can be used to analyze whether identifying and applying individual holding cost rates would be more cost effective than using one average rate.

It was pointed out in Chapter II that the effect on TVC of minor errors in the individual parameters is fairly small. Therefore, a large part of the potential savings resulting from more precise data can be realized if the relatively few items with holding cost rates far from the average can be identified.

The spreadsheet model was also used to analyze the impact of constraints imposed on the number of annual buys. The X-costs resulting from these constraints increase rapidly as the constraints get tighter. This conclusion was expected. The primary benefit of the model is that it can be easily adapted to various circumstances. Thus, changes in TVC caused by proposed policy changes, or other reasons, can readily be quantified.

D. RECOMMENDATIONS FOR FURTHER RESEARCH

The conclusion that ordering cost cannot be deter-mined by the number of purchase actions, has interesting ramifications for the use of EOQ formulae for inventory management. In this study, only data from SPCC were analyzed. A similar analysis should be done at other Inventory Control Points. If the same results were found, alternative inventory models should be evaluated. At any rate, different methods of determining the ordering cost parameter should be explored.

Presently, a holding cost rate of 23 percent is used for all consumables. This implies that all items have the same rate of obsolescence. This study indicates that savings can be realized by employing differentiated rates, based on

the inherent characteristics of the item. Further research would be needed to identify the true distribution of obsolescence rates, and to suggest a classifying scheme that would maximize the savings.

APPENDIX A

EXCERPT FROM DOD INSTRUCTION 4140.39

4140.39 Jul 17, 70
(Att 1 to Encl 3)

FUNCTIONAL ELEMENTS TO BE INCLUDED IN COST TO ORDER AT THE INVENTORY CONTROL POINT (ICP) LEVEL

I. DIRECT LABOR/ADP COSTS PER ITEM PROCURED AT ICP (Exclusive of Any Contract Administration Function Not Listed)

	Labor	ADP
A. Processing Purchase Request (PR) to Procurement		
1. Preparation of Documents Which Recommend the Buy	$____	$____
2. Item Manager Review if Applicable	____	____
3. Preparation of PR	____	____
4. Supervisory Review	____	____
5. Accounting Effort Related to Initiation, Commitment and Obligation of Funds	____	____
6. Establishment and Maintenance of Due-In Records	____	____
7. Internal Control of PR	____	____
8. Technical Coordination Associated with PR Preparation. (Does not include cost of maintaining technical data files, but does include cost of adding technical data to the PR whether accomplished manually or by automated process.) *May include:*	____	____
a. Cataloging and Standardization Review	(____)	(____)
b. Determination of Quality Control Provisions to be Inserted in Contract	(____)	(____)
c. Technical Decisions Concerning Source (Competitive Versus Non-competitive) and Engineering Data Requirements	(____)	(____)
d. Packing and Preservation Review	(____)	(____)
e. Provisioning Data Screening	(____)	(____)
f. Legal Review	(____)	(____)

1

Continuation of I.A.8.

g. Transportation Data Review	$(____)	$(____)
h. Review of Technical Handbook Adequacy	(____)	(____)

B. Purchase

Either subparagraphs 1 or 2 below will apply for the "purchase" function, depending on whether the value is below or above $2,500.

1. For Small Purchase Items	Labor	ADP
a. Receipt and Recording of PR	$ ____	$ ____
b. Solicitation Effort	____	____
(1) PR Review	(____)	(____)
(2) Determination of Method of Procurement	(____)	(____)
(3) Obtain Source List	(____)	(____)
(4) Draft and Type Solicitation	(____)	(____)
(5) Accomplish Solicitation	(____)	(____)
c. Evaluation and Award Effort	____	____
(1) Price/Cost Analysis	(____)	(____)
(2) Selection of Contractor	(____)	(____)
(3) Draft and Type Contract	(____)	(____)
(4) Purchase Office Review	(____)	(____)
(5) Legal Review	(____)	(____)
(6) Distribution of Contract	(____)	(____)

2. For All Other Items

(For Call-Type Contracts, include only those functions relating to the processing of orders.)

a. Receipt and Recording of PR and Assignment of Buyer	____	____

Continuation of I.B.2.

	Labor	ADP
b. Solicitation Effort	$ ____	$ ____
(1) Procurement Planning	(____)	(____)
(2) PR Review and Small Business Coordination	(____)	(____)
(3) Determination and Finding	(____)	(____)
(4) Determination of Type Contract	(____)	(____)
(5) Synopsis and/or Preliminary Invitation Notice	(____)	(____)
(6) Draft and Type Solicitation	(____)	(____)
(7) Accomplish Solicitation	(____)	(____)
c. Evaluation and Award Effort	____	____
(1) Receive Quotes and Proposals	(____)	(____)
(2) Opening of Bids	(____)	(____)
(3) Evaluation (Technical, Procurement, Production, Transportation)	(____)	(____)
(4) Selection of Probable Contractor	(____)	(____)
(5) Selection of Contractor	(____)	(____)
(6) Procurement/Legal Review	(____)	(____)
(7) Draft and Type Contract	(____)	(____)
(8) Process Administrative Commitment Document	(____)	(____)
(9) Forwarding of Contract to Contractor for Signature	(____)	(____)
(10) Receipt of Contract and Final Review, Signature	(____)	(____)
(11) Obligation of Funds	(____)	(____)
(12) Distribution of Contract and Final Administrative Procedures	(____)	(____)

Continuation of I.

	Labor	ADP
C. Receipt and Payment		
1. Unload and Check-in of Materiel Received	$ ____	$ ____
2. Quality Inspection	____	____
3. Matching Receipt Papers	____	____
4. Relocation of Materiel During Receipt Processing	____	____
5. Movement of Materiel to Warehouse	____	____
6. Updating Storage Location and Asset Records	____	____
7. Updating ICP Asset Records	____	____
8. Processing DD 250 and Invoices for Payment	____	____
9. Other Financial Effort Related to Payment	____	____

II. DIRECT LABOR/ADP COST PER ITEM ADMINISTERED AT A DEFENSE CONTRACT ADMINISTRATION SERVICES REGION (DCASR)

Note: These costs will be determined by Defense Contract Administration Services (DCAS) and Defense Contract Audit Agency (DCAA) and published by OASD(I&L) for use by all Military Departments and the Defense Supply Agency.

	Labor	ADP
A. Initial File Establishment	____	____
B. Pre-award Survey	____	____
C. Price/Cost Analyses	____	____
D. Production Follow-up	____	____

III. LABOR BENEFIT COSTS (See DODI 7041.3)

A. Personnel benefits (health insurance, retirement, life insurance, disability) will be computed at 8% of direct labor cost. ____

Continuation of III.

	Labor	ADP
B. Leave entitlements to cover sick and annual leave, holiday leave, administrative leave will be computed at 21% of direct labor cost.	____	

IV. INDIRECT LABOR/SUPPORT COSTS NOT INCLUDED IN I AND II	Total $
A. Communication Costs (Autodin, Telephone, Teletype)	____
B. Internal Reproduction Equipment Rental	____
C. Cost of Printing PRs and Contracts	____
D. Materiel and Supplies	____
E. Cost of Mail	____
F. Data Service (Key Punch, Sort, the Variable Automatic Data Processing Costs Associated with Each Function)	____
G. Personnel Support (Civilian Personnel Office)	____

V. TOTAL VARIABLE COST TO ORDER	
Sum of Direct Labor/ADP Cost at ICP	____
Sum of Direct Labor/ADP Cost at DCASAR	____
Sum of Labor Benefit Cost	____
Sum of Indirect Labor/Support Costs	____
TOTAL	____

APPENDIX B

ORDERING COST COMPUTATIONS AT SHIPS PARTS CONTROL CENTER

Appendix B is included to present how ordering cost parameters are computed at Ships Parts Control Center (SPCC).

5200
Ser 0711/24

AUG 1 0 1988

MEMORANDUM

From: 07
To: 001

Subj: ADMINISTRATIVE COSTS OF PROCUREMENT

Ref: (a) DoD Instruction 4140.39 of 17 Jul 70
(b) COMNAVSUP ltr 7113 Ser 01328/105/B41 of 23 Feb 88
(c) 04 memo 5200 Ser 0412/457 of 28 Aug 85

Encl: (1) Administrative Costs of Procurement
(2) Summary of Source Data

1. In accordance with the direction of the Inventory Requirements Council (IRC) chairman, the annual revision of administrative costs of procurement has been completed by a committee composed of representatives from Codes 01, 02, 03, 04 and 07. The report is based on the policy established in reference (b). Enclosure (1) shows the updated costs for the various purchase documents and a summary of source data is included as enclosure (2).

2. Only variable costs associated with the determination of the requirement, processing of the purchase request, and subsequent contract action are included. Costs are considered "fixed" if they would remain constant should 50 percent of the workload be eliminated.

3. Manufacturers set up costs that were recommended in reference (c) are also included in the following projections:

	Current	Projected
Purchase Order	$653.58	$729.36
Delivery Order	$631.80	$700.77
Negotiated Contract	$2,026.65	$1,820.48
Advertised Contract	$1,701.22	$1,729.10

4. Point of contact is Rex Taylor, Code 0711, extension 3683.

Very Resp.

H E Boswell

H. E. Boswell

Copy to:
01
02
03
04
05
84
87

PROJECTED FY89

ADMINISTRATIVE COSTS OF PROCUREMENT
(LINE ITEM)

55,195 LINE ITEMS VARIABLE DIRECT COSTS	TOTAL LABOR COSTS	COST PER LINE ITEM	TOTAL ADP COSTS	COST PER LINE ITEM	TOTAL MISC COSTS	COST PER LINE ITEM	38,102 PURCHASE ORDER L.I.	10,976 DELIVERY ORDER L.I.	5,940 NEGOTIATED CONTRACT L.I.	[illegible] CONTRACT L.I.
Inventory Management	1,056,780	19.15					19.15	19.15	19.15	19.15
Data Processing			594,967	10.78			10.78	10.78	10.78	10.78
Requisition Processing	314,054	5.69					5.69	5.69	5.69	5.69
Data Processing			149,489	2.71			2.71	2.71	2.71	2.71
Technical Support	5,827,272	105.58					105.58	105.58	105.58	105.58
Data Processing			180,645	3.27			3.27	3.27	3.27	3.27
Breakout	5,839,713	105.80					105.80	105.80	105.80	105.80
Data Processing			28,856	.52			.52	.52	.52	.52
Contracting										
Overhead	1,710,355	30.99					13.24	13.24	173.36	173.36
Large	5,436,476	888.74							892.66	750.63
Small	3,385,035	73.05					74.45	49.95		
Data Processing			1,019,232	18.47			18.47	18.47	18.47	18.47
Financial Control	4,579,915	82.98					82.98	82.98	82.98	82.98
Data Processing			476,311	8.63			8.63	8.63	8.63	8.63
Misc Labor (SPCC										
Counsel	453,149	8.21					3.51	3.51	45.93	45.93
Transportation	68,581	1.24					1.24	1.24	1.24	1.24
Small Business	85,179	1.54					1.54	1.54	1.54	1.54
Technical Library	741,802	13.44					13.44	13.44	13.44	13.44
Total Labor	29,498,311									
Personnel Support	501,471	9.09					9.09	9.09	9.09	9.09
Training	466,073	8.44					8.44	8.44	8.44	8.44
Total Labor/ADP	30,465,855						488.53	464.64	15[illegible].45	[illegible]
Salary Increase (4%)	1,218,634						17.77	16.78	58.59	50.91

Enclosure (1)

PROJECTED FY89

ADMINISTRATIVE COSTS OF PROCUREMENT (CON'T)
(LINE ITEM)

55,195 LINE ITEMS VARIABLE DIRECT COSTS	TOTAL LABOR COSTS	COST PER LINE ITEM	TOTAL ADP COSTS	COST PER LINE ITEM	TOTAL MISC COSTS	COST PER LINE ITEM	38,102 PURCHASE ORDER L.I.	10,976 DELIVERY ORDER L.I.	5,940 NEGOTIATED CONTRACT L.I.	177 ADVERTISED CONTRACT L.I.
Miscellaneous SPCC	31,684,489									
Communications					780,250	14.14	14.14	14.14	14.14	14.14
Xerox					48,000	.87	.87	.87	.87	.87
Printing					631,593	11.44	8.80	8.80	32.62	32.62
Drawings					181,354	3.29	3.11		8.64	65.17
Sub Total	31,684,489	574.04	[illegible]	[illegible]	1,641,197	29.74	573.22	504.63	1624.34	1532.96
Added External Costs	2,546,697						46.14	46.14	46.14	46.14
MFG's Set Up	8,279,250						150.00	150.00	150.00	150.00
Total Costs	46,601,263	844.30								
Cost Per Line Item							729.36	700.77	1820.48	1729.10

2

ADMINISTRATIVE COST OF PROCUREMENT
SUMMARY OF SOURCE DATA

1. Procurement costs reflect the policy and direction established in DoD Instruction 4140.39, Procurement and Safety Levels of Supply for Secondary Items. Costs are based on the projected number of line items that will be acquired during FY89. Projected line items were calculated by using the number of pruchase actions reported on the DD350 and DD1057 reports multiplied by the average number of line items which was determined by a review of the various procurement documents.

2. Line items that were completed through the use of estimated orders were not included, since these multi-line documents are for the most part written to satisfy initial provisioning requirements. The inclusion of these items would greatly reduce procurement cost and would not accurately reflect the actual cost of replenishment type actions. Also excluded are BPA calls, since these are used in the procurement of base support items.

3. Labor costs for all operations are based on data reported on the Uniform Management Report (UMR) during the first three quarters of FY88, annualized for 12 months. Costs for inventory management were prorated, based on procurement actions as a percentage of total manual supply actions. Inventory Management cost accounts used were ICP Demand Review and Other Inventory Management, as well as the corresponding job order number (JON) information for SPCC Codes 84 and 87. Repairables labor costs and work units were not included.

4. Costs for requisition processing were prorated based on procurement/reconsignments, as a percentage of total manual requisitions. Cost accounts included Requisition Processing and Requisition Expediting, as well as the corresponding JON information for SPCC Codes 84 and 87.

5. Comptroller labor costs include only inventory management related costs (1C4A, 1C4[illegible], 1C4F and 1C1D).

6. Technical costs include only those related to Cost Account 2570, Technical Support and the corresponding JON information for SPCC Codes 84 and 87.

7. Contracting costs are based on UMR data that are identified to the various types of purchase documents, including the Breakout (Competition) costs applicable to the Contracting operation.

8. Total printing costs were based on billings by NPPSDO. Costs for various documents were based on the average number of pages in each type of document.

9. Technical library costs are based on UMR data and the average number of drawings required for each document.

10. Drawing production represents the material costs to produce the applicable aperture cards.

11. Breakout costs include all full and limited screen breakout efforts.

12. Communications and Xerox costs were based on comptroller data.

Enclosure (2)

13. Costs for personnel leave and fringe benefits were included in the UMR figures for the various cost accounts/JONs in each category.

14. Data processing costs are taken from the second quarter FY88 Data Processing Services Billing Report (JCN CA0026).

15. Cost for military personnel salaries were excluded.

16. Hours expended on cancellations and reconsignments were included in the total; however, line items processed by these methods were excluded since no line items were actually procured by reconsigning or cancelling.

17. Added external costs are provided in the COMNAVSUP letter 7113 0132B/0857E/B41 of 23 February 1988.

18. Personnel Support costs are prorated based on the total cost to order labor costs as a percentage of total SPCC labor costs.

19. Set up costs are identified in the Code 04 memo 5200 Ser 0412/457 of 28 August 1985.

20. Contracting overhead labor costs were prorated to the small/large categories based on the UMR labor charges to the small/large contracting accounts.

21. Total labor charges were increased by four percent based on an anticipated pay raise for FY89.

APPENDIX C

EOQ SIMULATION MODEL

Appendix C presents the EOQ model used to compute X-cost, the cost of ordering quantities that differ from the theoretically optimal. The model was built using LOTUS 1-2-3 software.

INVENTORY MODEL FOR SIMULATION

INPUT PARAMETERS:

	SMALL	LARGE	SLOW	TOTAL
LINE ITEMS:	45000	5000	50000	100000
DEMAND (D):	8	12	0.25	
PRICE (C):	250	5000	800	
ORDER COST (A):	700	1700	700	

CONSTRAINT: NUMBER OF BUY PER YEAR
MAX: 4
MIN: 1/12

SIMULATION VARIABLE:

HOLDINC COST (I):	0.23	0.23	0.23	
INTERMEDIATE RESULTS ASSUMING I=.23 (WITH CONSTRAINTS)				
HOLDING COST/ITEM:	57.5	1150	184	
EOQ PER LINE ITEM:	13.95645	5.956363	1.379193	
CONSTRAINED EOQ:	13.95645	5.956363	1.379193	
BUYS PER YEAR (N):	0.573211	2.014652	0.181265	
TOTAL BUYS/YEAR:	25795	10073	9063	44931
HOLDING COSTS:	401.2480	3424.908	126.8857	
ORDERING COSTS:	401.2480	3424.908	126.8857	
TVC:	802.4961	6849.817	253.7715	

ASSUMING "I" IS A RANDOM VARIABLE:

HOLDING COST/ITEM:	57.5	1150	184	
EOQ PER LINE ITEM:	13.95645	5.956363	1.379193	
CONSTRAINED EOQ:	13.95645	5.956363	1.379193	
BUYS PER YEAR (N):	0.573211	2.014652	0.181265	
TOTAL/BUYS/YEAR:	25795	10073	9063	44931
HOLDING COSTS:	401.2480	3424.908	126.8857	
ORDERING COSTS:	401.2480	3424.908	126.8857	
TVC:	802.4961	6849.817	253.7715	

COSTS OF "I" BEING UNKNOWN:

HOLDING COSTS:			
INCURRED:	401.2480	3424.908	126.8857
OPTIMAL:	401.2480	3424.908	126.8857
EXTRA HOLDING:	0	0	0
ORDERING:			
INCURRED:	401.2480	3424.908	126.8857
OPTIMAL:	401.2480	3424.908	126.8857
EXTRA ORDERING:	0	0	0
ADD'L COST/ITEM:	0	0	0
TOT. ADD'L COSTS:	0	0	0

SIMULATION OBJECTIVE:	0.000000
INCURRED TOTAL COSTS:	83049989
CONSTRAINT COSTS:	0

TRIANGULAR

.11	0
.23	1
.31	0

The simulation was done using a program from the ENFIN Software Corporation. The following is a sample of the output from the the program.

Objective	Cur. Value	Most Likely	Average	Std.Dev
D49	0.00	1396.18	396851.75	597906

Variable	Type	Par 1	Par 2	Count Va
C11	Triangular	F50..G52		

Distribution	Dist. %	Dist. #	Accl. %	Accl. #
0.00	69.35	1387	69.35	1397
385344.41	15.75	315	85.10	1702
770688.82	5.45	109	90.55	1811
1156033.24	2.95	59	93.50	1870
1541377.65	2.10	42	95.60	1912
1926722.06	1.90	36	97.40	1948
2312066.47	1.55	31	98.95	1979
2697410.88	0.50	10	99.45	1989
3082755.29	0.30	6	99.75	1995
3468099.70	0.25	5	100.00	2000
3853444.11				

Parameters	
Display Precision	2
Number of Samples to Run	2000
Number of lines to display	10

The remainder of this appendix is a printout of the cell formulae of the EOQ model.

```
A1:  'INVENTORY MODELS FOR SIMULATION
A2:  \-
B2:  \-
C2:  \-
A3:  'INPUT PARAMETERS:
C4:  "SMALL
D4:  "LARGE
E4:  "SLOW
F4:  "TOTAL
G4:  'CONSTRAINT N/YEAR
A5:  'LINE ITEMS:
C5:  45000
D5:  5000
E5:  50000
F5:  +C5+D5+E5
G5:  'MAX:
H5:  1
A6:  'DEMAND (D):
C6:  8
D6:  12
E6:  0.25
G6:  'MIN:
H6:  1/3
A7:  'PRICE (C):
C7:  250
D7:  5000
E7:  800
A8:  'ORDER COST (A):
C8:  700
D8:  1700
E8:  700
A10:  'SIMULATION VARIABLE:
A11:  'HOLDINC COST (I):
C11:  0.23
D11:  +C11
E11:  +D11
A13:  'INTERMEDIATE RESULTS ASSUMING I=.23
E13:  ' WITH CONSTRAINTS
A15:  'HOLDING COST/ITEM:
C15:  0.23*C7
D15:  0.23*D7
E15:  0.23*E7
A16:  'EOQ PER LINE ITEM:
C16:  @SQRT(2*C8*C6/C15)
D16:  @SQRT(2*D8*D6/D15)
E16:  @SQRT(2*E8*E6/E15)
A17:  'CONSTRAINED EOQ:
C17:  +C6/C18
D17:  +D6/D18
E17:  +E6/E18
G17:  '
H17:  '
A18:  'BUYS PER YEAR (N):
C18:  @IF(C6/C16>$H$6,@IF(C6/C16<$H$5,C6/C16,$H$5),$H$6)
D18:  @IF(D6/D16>$H$6,@IF(D6/D16<$H$5,D6/D16,$H$5),$H$6)
E18:  @IF(E6/E16>$H$6,@IF(E6/E16<$H$5,E6/E16,$H$5),$H$6)
A19:  'TOTAL BUYS/YEAR:
C19:  @ROUND(C18*C5,0)
D19:  @ROUND(D18*D5,0)
E19:  @ROUND(E18*E5,0)
F19:  +C19+D19+E19
A20:  'HOLDING COSTS:
C20:  +C6/C18*C15/2
D20:  +D6/D18*D15/2
E20:  +E6/E18*E15/2
A21:  'ORDERING COSTS:
C21:  +C18*C8
```

```
D21: +D18*D8
E21: +E18*E8
A22: 'TVC:
C22: +C20+C21
D22: +D20+D21
E22: +E20+E21
A23: '
A24: 'ASSUMING "I" IS A RANDOM VARIABLE:
A26: 'HOLDING COST/ITEM:
C26: +$C$11*C7
D26: +$C$11*D7
E26: +$C$11*E7
A27: 'EOQ PER LINE ITEM:
C27: @SQRT((2*C8*C6)/($C$11*C7))
D27: @SQRT((2*D8*D6)/($C$11*D7))
E27: @SQRT((2*E8*E6)/($C$11*E7))
A28: 'CONSTRAINED EOQ:
C28: +C6/C29
D28: +D6/D29
E28: +E6/E29
A29: 'BUYS PER YEAR (N):
C29: @IF(C6/C27>$H$6,@IF(C6/C27<$H$5,C6/C27,$H$5),$H$6)
D29: @IF(D6/D27>$H$6,@IF(D6/D27<$H$5,D6/D27,$H$5),$H$6)
E29: @IF(E6/E27>$H$6,@IF(E6/E27<$H$5,E6/E27,$H$5),$H$6)
A30: 'TOTAL/BUYS/YEAR:
C30: @ROUND(C29*C5,0)
D30: @ROUND(D29*D5,0)
E30: @ROUND(E29*E5,0)
F30: +C30+D30+E30
A31: 'HOLDING COSTS:
C31: +C26*C28/2
D31: +D26*D28/2
E31: +E26*E28/2
A32: 'ORDERING COSTS:
C32: +C8*C29
D32: +D8*D29
E32: +E8*E29
A33: 'TVC:
C33: +C31+C32
D33: +D31+D32
E33: +E31+E32
A35: 'COSTS OF "I" BEING UNKNOWN:
A36: 'HOLDING COSTS:
A37: 'INCURRED:
C37: +$C$11*C7*C17/2
D37: +$C$11*D7*D17/2
E37: +$C$11*E7*E17/2
A38: 'OPTIMAL:
C38: +C31
D38: +D31
E38: +E31
A39: 'EXTRA HOLDING:
C39: +C37-C38
D39: +D37-D38
E39: +E37-E38
```

```
A41: 'ORDERING:
A42: 'INCURRED:
C42: +C8*C18
D42: +D8*D18
E42: +E8*E18
A43: 'OPTIMAL:
C43: +C32
D43: +D32
E43: +E32
A44: 'EXTRA ORDERING:
C44: +C42-C43
D44: +D42-D43
E44: +E42-E43
A46: 'ADD'L COST/ITEM:
C46: +C39+C44
D46: +D39+D44
E46: +E39+E44
A47: 'TOT. ADD'L COSTS:
C47: +C5*C46
D47: +D5*D46
E47: +E5*E46
A49: 'SIMULATION OBJECTIVE:
D49: +C47+D47+E47
F49: 'TRIANGULAR
A50: 'INCURRED TOTAL COSTS:
D50: +C5*(C37+C42)+D5*(D37+D42)+E5*(E37+E42)
F50: 0.11
G50: 0
A51: 'CONSTRAINT COSTS:
D51: @ROUND(83049990-D50,0)/1000
F51: 0.23
G51: 1
F52: 0.31
G52: 0
```

LIST OF REFERENCES

1. Tersine, Richard J., Principles of Inventory Management, 3rd edition, New York, North-Holland, 1988.

2. Stockton, Robert Stransbury, Basic Inventory Systems: Concept and Analysis, Boston, Allyn and Bacon, Inc., 1965.

3. Jannis, C. Paul, Poedtke, Carl H. Jr., and Ziegler, Donald R., Managing and Accounting for Inventories, 3rd edition, New York, John Wiley & Sons, 1980.

4. Van DeMark, R. L., Inventory Control Techniques, Dallas. Van DeMark, Inc., 1981.

5. Lambert, Douglas M., The Development of an Inventory Costing Methodology: A Study of the Costs Associated With Holding Inventory, A Research Report published by National Council of Physical Distribution Management, Chicago 1975.

6. Goodman, Sam R., Financial Manager's Manual and Guide, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1973.

7. Ballou, Ronald H., Business Logistics Management, 2nd edition, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1985.

8. Mao, James C. T., Quantitative Analysis of Financial Decisions, Toronto, Canada, Collier-Mcmillan Canada, Ltd., 1969.

9. Hadley, G., and Whitin, T. M., Analysis of Inventory Systems, Englewood Cliffs, New Jersey, Prentice Hall, Inc.,1963.

10. Demski, Joel S., and Feltham, Gerald A., Cost Determination: A Conceptual Approach, Iowa State University Press, Ames, 1976.

11. Brigham, Eugene F., and Gapenski, Lois C., Financial Management Theory and Practice, 5th edition, The Dryden Press, New York 1988.

12. Krupp, James A.G., "Obsolescence: the Neglected Factor," Management Accounting, September, 1977.

13. Naval Supply Systems Command Publication 553, Inventory Management.

14. Naval Materiel Command Instruction 4423.8, Wholesale System Stockage Policy for Nondemand Based Items, 8 March, 1982.

15. Department of Defense Instruction 4140.39, Procurement Cycles and Safety Levels of Supply for Secondary Items, 31 December 1985

16. Austin, Larry M., "Project EOQ: A Success Story in Implementing Academic Research," Interfaces, Vol 7, No 4, August 1977.

17. Interview between Mr. J. Boyarski, Ships Parts Control Center, Mechanicsburg, Pennsylvania, and the author, 5 October 1988.

18. Interview between Mr. J. G. Heinold Jr., Ships Parts Control Center, Mechanicsburg, Pennsylvania, and the author, 6 October 1988.

19. Interview between Mr. E. Evelhoch, Ships Parts Control Center, Mechanicsburg, Pennsylvania, and the author, 5 October 1988.

20. Office of Management and Budget, Circular No. A-94, Washington, D.C., 1972.

21. Sassone, Peter G., and Schaffer William A., Cost Benefit Analysis - A Handbook, Academic Press, Inc., San Diego, 1978.

22. Interview between R. Sanders, Commander SC, USN, Naval Supply Center, Oakland, California, and the author, 17 September 1988.

23. Interview between Mr. W. Smith, Ships Parts Control Center, Oakland, California, and the author, 6 October 1988.

24. Naval Supply Systems Command, Strategic Plan FY 1988, p. 2-B-7, Washington, D.C.

25. Fleet Material Support Office, Report 139, An Economic Retention Model for Excess Navy Material, by J. F. Harper, p. 6, March 1980.

26. Interview between Mr. R. Taylor, Ships Parts Control Center, Mechanicsburg, Pennsylvania, and the author 6 October 1988.

27. Ships Parts Control Center Memorandum 5200: Serial 0711/24, Subject: Administrative Costs of Procurement, 10 August 1988.

INITIAL DISTRIBUTION LIST

1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5000	2
3.	Commanding Officer Ships Parts Control Center 5450 Carlisle Pike Attn: Mr. Emerson Evelhoch P.O.Box 2020 Mechanicsburg, Pennsylvania 17055-0788	2
4.	Commanding Officer Fleet Material Support Office 5040 Carlisle Pike P.O.Box 2010, Code 93 Mechanicsburg, Pennsylvania 17055-0787	3
5.	Forsvarets overkommando Sjøforsvarsstaben/ORG-2 Oslo Mil/Huseby 0016 OSLO 1 NORWAY	1
6.	Sjøforsvarets forsyningskommando Postboks 3 N-5078 Haakonsvern NORWAY	1
7.	Sjøkrigsskolen Postboks 25 N-5034 Ytre Laksev NORWAY	1
8.	KNM Tordenskjold SADS N-5078 Haakonsvern NORWAY	1

9. Morten Meinich 2
Fantoftåsen 11
N-5032 Minde
NORWAY

10. Shu S. Liao 1
Administrative Sciences Department
Code 54 Lc
Naval Postgraduate School
Monterey, California 93943-5000

11. Thomas P. Moore 1
Administrative Sciences Department
Code 54 Mr
Naval Postgraduate School
Monterey, California 93943-5000

12. Roger D. Evered 1
Administrative Sciences Department
Code 54 Ev
Naval Postgraduate School
Monterey, California 93943-5000